Weather Radar Dual Polarization Technology And Penn State's Ionosphere Research Laboratory

Thomas A. Seliga

On August 23, 2012, the U.S. National Oceanic Atmospheric Administration (NOAA) posted a statement on the internet about a ***Life-saving technology upgrade coming to a Doppler radar near you[1].*** The purpose of this posting was to alert the public to the implementation of a 'new technology' termed *dual polarization* that was deemed as being the most significant enhancement ever made to the nation's weather radar network since Doppler radar was first installed in the early 1990's. The upgrade will provide better information about the type of precipitation in the atmosphere and its intensity, size and location; it will also increase the accuracy of forecasts and allow for more accurate and timely warnings, giving the public better information to protect their lives and property. At the time, NOAA's National Weather Service was half-way through upgrading its network of 160 Doppler weather radars throughout the nation with this new technology. On April 25, 2013, NOAA posted a follow-up statement entitled ***Dual-polarization radar: Stepping stones to building a Weather-Ready Nation[2]***, announcing completion of the upgrade. These statements are among many issued by NOAA and its constituent organizations such as the National Severe Storms Laboratory (NSSL) and the WSR-88D (Weather Surveillance Radar - 1988 Doppler) Radar Operations Center (ROC) on the development, impact and operational utility of dual polarization technology. NOAA claims that they developed the technology through decades of research at its National Severe Storms Laboratory (NSSL). This Laboratory has indeed done admirable work in dual polarization, but this representation is far from complete and does not adequately account for the historical record, since very important fundamental research at many other organizations worldwide preceded NOAA's involvement. This presentation will review these efforts, and show that research at Penn State's Ionosphere Research Laboratory (IRL) and my personal experiences while a student and faculty member in IRL were key to the development of dual polarization weather radar technology. Of particular scientific relevance was the success of radio wave interaction studies by Tony Ferraro, Hai Sup Lee and Steve Weisbrod at IRL that demonstrated the efficacy of achieving high precision differential amplitude and phase measurements in their radio wave interaction experiments to probe the D-region of the ionosphere.

The story is necessarily personal and relates also to my role as Director of the Atmospheric Sciences Program (ASP) at Ohio State University during the 1970's and early 1980's. The story began while on leave of absence from Penn State to serve the National Science Foundation Atmospheric Sciences Section as Program Director for Aeronomy in 1967-68. I learned that weather radar did a very poor job in measuring rainfall rate and that radar meteorologists were struggling to find an answer. Later on, my tenure and responsibilities at Ohio State afforded me

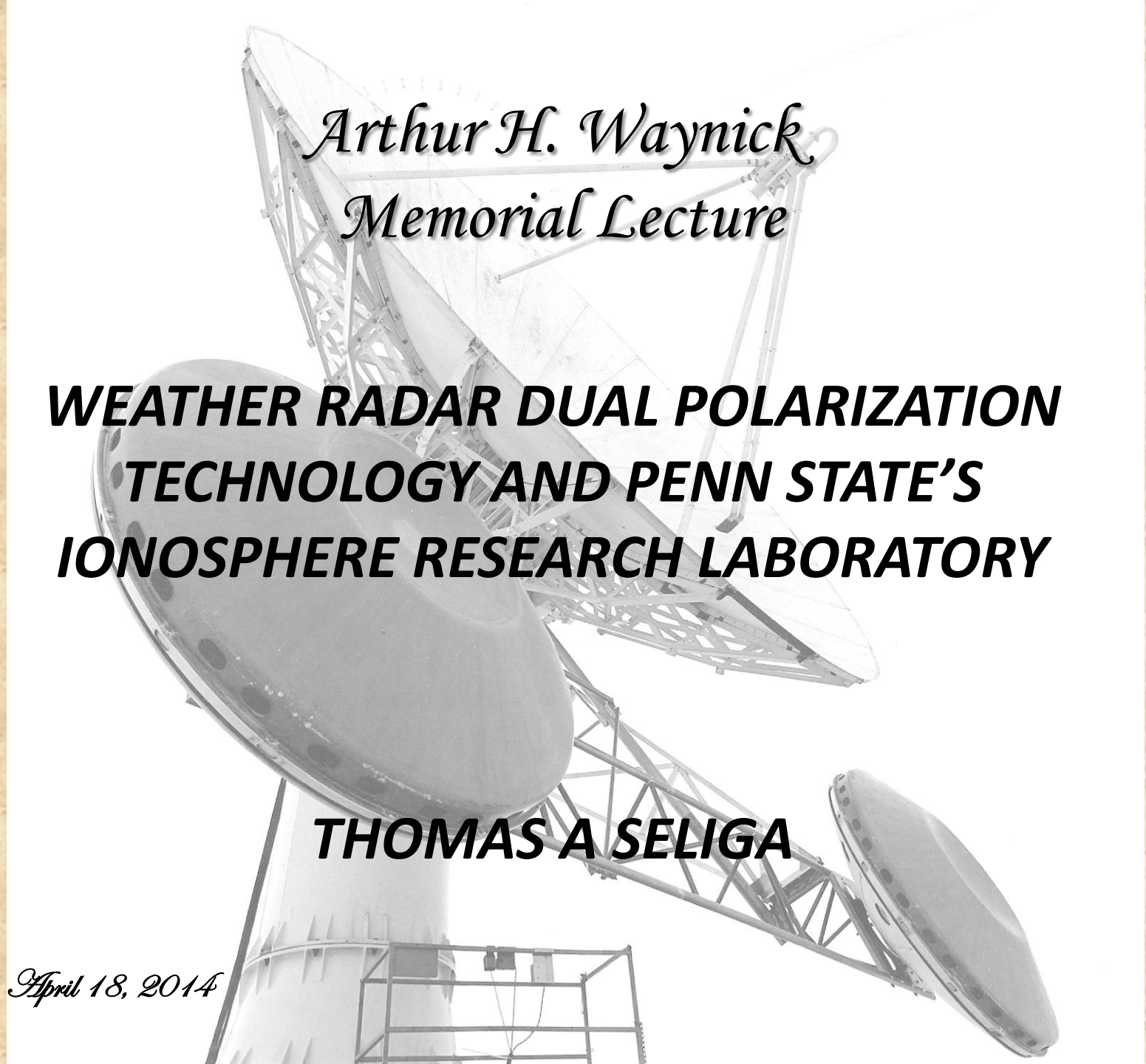
[1] http://www.nws.noaa.gov/com/weatherreadynation/news/080212_dual.html

[2] http://www.nws.noaa.gov/com/weatherreadynation/news/130425_dualpol.html

the opportunity to address this problem and led to conceptualizing the linear-based (horizontal and vertical), dual polarization radar parameters of differential reflectivity Z_{DR} in 1974 and specific differential phase shift K_{DP} in 1978 as means for improving the quantitative estimation of rainfall rate. We also found that Z_{DR} could be used for hail detection and discriminating between hydrometeor particles such as snowfall and rainfall. Scientists at national weather radar facilities such as NSSL, the NASA Goddard Space Flight Center, the National Center for Atmospheric Research (NCAR) and the US Air Force Cambridge Research Laboratories (AFCRL) were not very receptive to our requests to perform the critical proof-of-concept experiments. Thankfully though, Dr. Gene Mueller at the University of Illinois' State Water Survey (operator of the NSF-funded CHILL weather radar) responded favorably and provided us the first data that confirmed the efficacy of the Z_{DR} concept. Shortly thereafter, we found another major contributor to this effort. The UK's Appleton Laboratory (AL) (currently incorporated within the Rutherford Appleton Laboratory and with whom we established a research collaboration with NATO support) was favorable to our ideas and interested in using Z_{DR} as a key parameter for studying effects of precipitation along earth-satellite communication paths. Consequently, the AL altered their new high resolution radar design to include Z_{DR} measurements. Their initial radar measurements were highly successful and helped immensely by not only further validating our first measurements but also by furthering dual polarization research throughout the world. It should be noted that the aforementioned research resides within a much larger body of knowledge; especially noteworthy in this regard are the studies of the National Research Council of Canada that focused its attention on circular polarization measurements. All of these investigations occurred long before NOAA entered the field of dual polarization research.

It is of interest to note that Dr. Waynick studied ionospheric wave propagation with Sir Edward Appleton when he attended Cambridge University as a Guggenheim Fellow in the late 1930's!

In conclusion and most importantly, the nation has finally begun to benefit from a technological upgrade in weather radar technology that is at least 40 years old! Furthermore, the worldwide consensus is that the technology is not only of great operational utility but will remain a major tool for weather-related research for decades to come. Many of these areas will be identified.



Arthur H. Waynick Memorial Lecture

WEATHER RADAR DUAL POLARIZATION TECHNOLOGY AND PENN STATE'S IONOSPHERE RESEARCH LABORATORY

THOMAS A SELIGA

April 18, 2014

LITTLE-KNOWN OR APPRECIATED MAJOR ACADEMIC CONTRIBUTIONS OF DR. ARTHUR H. WAYNICK TO PENN STATE UNIVERSITY

1. ENGINEERING SCIENCE MAJOR
2. MULTIDISCIPLINARY RESEARCH AND GRADUATE STUDIES
3. DEPARTMENT OF ASTRONOMY AND ASTROPHYSICS
4. LEGACY OF RESEARCH AND RELATED TECHNOLOGIES

1. **ENGINEERING SCIENCE (ES) MAJOR**

   Support of Professor Jack Mentzer as Academic Advisor

   Assigning the very best EE teachers to ES courses

2. **MULTIDISCIPLINARY RESEARCH AND GRADUATE STUDIES**

   Involvement of faculty and students from other departments such as Physics, Engineering Mechanics, Aeronautical Engineering, Chemistry and Mathematics

3. **DEPARTMENT OF ASTRONOMY AND ASTROPHYSICS**

   Provided strong support and leadership towards the University's initial efforts to develop a nationally recognized Department of Astronomy

4. **LEGACY OF RESEARCH AND RELATED TECHNOLOGIES**

(AFCRC - TN - 55-461)

THE PENNSYLVANIA
STATE UNIVERSITY

IONOSPHERIC RESEARCH

Scientific Report No. 75

"Methods of Determining Long Wave Reflection Coefficients for a Specific Ionospheric Model"

by

J. J. Gibbons and J. D. Wolf

IONOSPHERE RESEARCH LABORATORY

University Park, Pennsylvania

Contract No. AF19(604)-1304

J. J. GIBBONS AND J. D. WOLF

AFCRL-62-409

THE PENNSYLVANIA
STATE UNIVERSITY

IONOSPHERIC RESEARCH

Scientific Report No. 155

A REPRESENTATION OF THE TERRESTRIAL ATMOSPHERE FROM 100 KM TO 3000 KM

by

Marcel Nicolet

February 1, 1962

The research reported in this document has been sponsored by the Geophysics Research Directorate of the Air Force Cambridge Research Laboratory, Air Research and Development Command, under Contract AF19(604)-4563 and, in part, by the National Science Foundation under Grant G-18983.

IONOSPHERE RESEARCH LABORATORY

University Park, Pennsylvania

Contract No. AF19(604)-4563

MARCEL NICOLET

IONOSPHERE RESEARCH LABORATORY SCIENTIFIC REPORTS

Other Insights into Dr. Waynick's Career and Contributions

- President Eric Walker's National Academy of Engineering Tribute

  http://www.nap.edu/openbook.php?record_id=565&page=291

- Dr. Philip Mange's Oral History Transcript on behalf of the American Institute of Physics

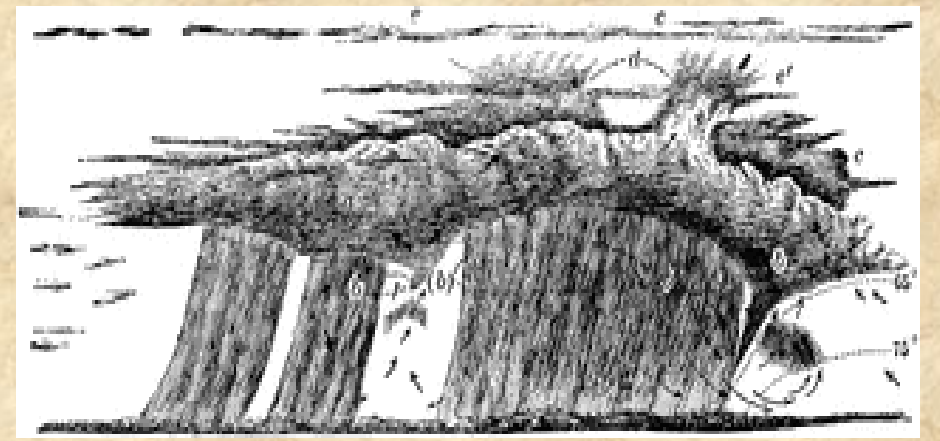
  http://www.aip.org/history/ohilist/31144_2.html

Some Personal Anecdotes

- Getting the job done!
  - Confidence in his staff to get the job done
  - Rarely, if ever, second-guessed people
  - Always thinking of how to assist faculty and students by referring them to the latest and greatest
  - The dreaded early morning call

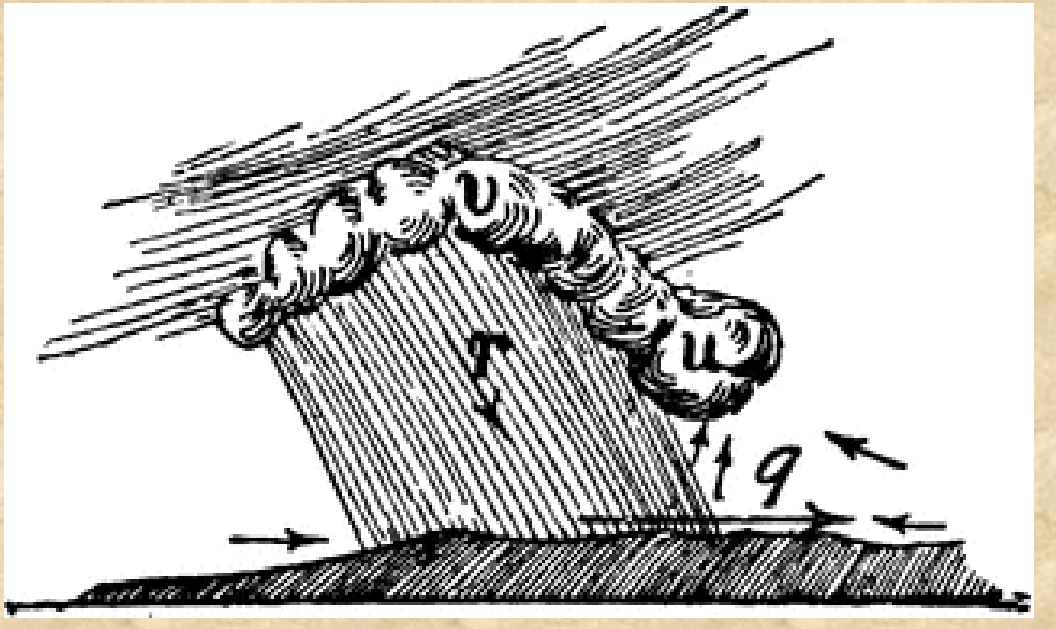
IT'S ALL ABOUT THE RAIN AND OTHER FORMS OF PRECIPITATION AND THEIR IMPACTS

FLOODS



THUNDERSTORMS

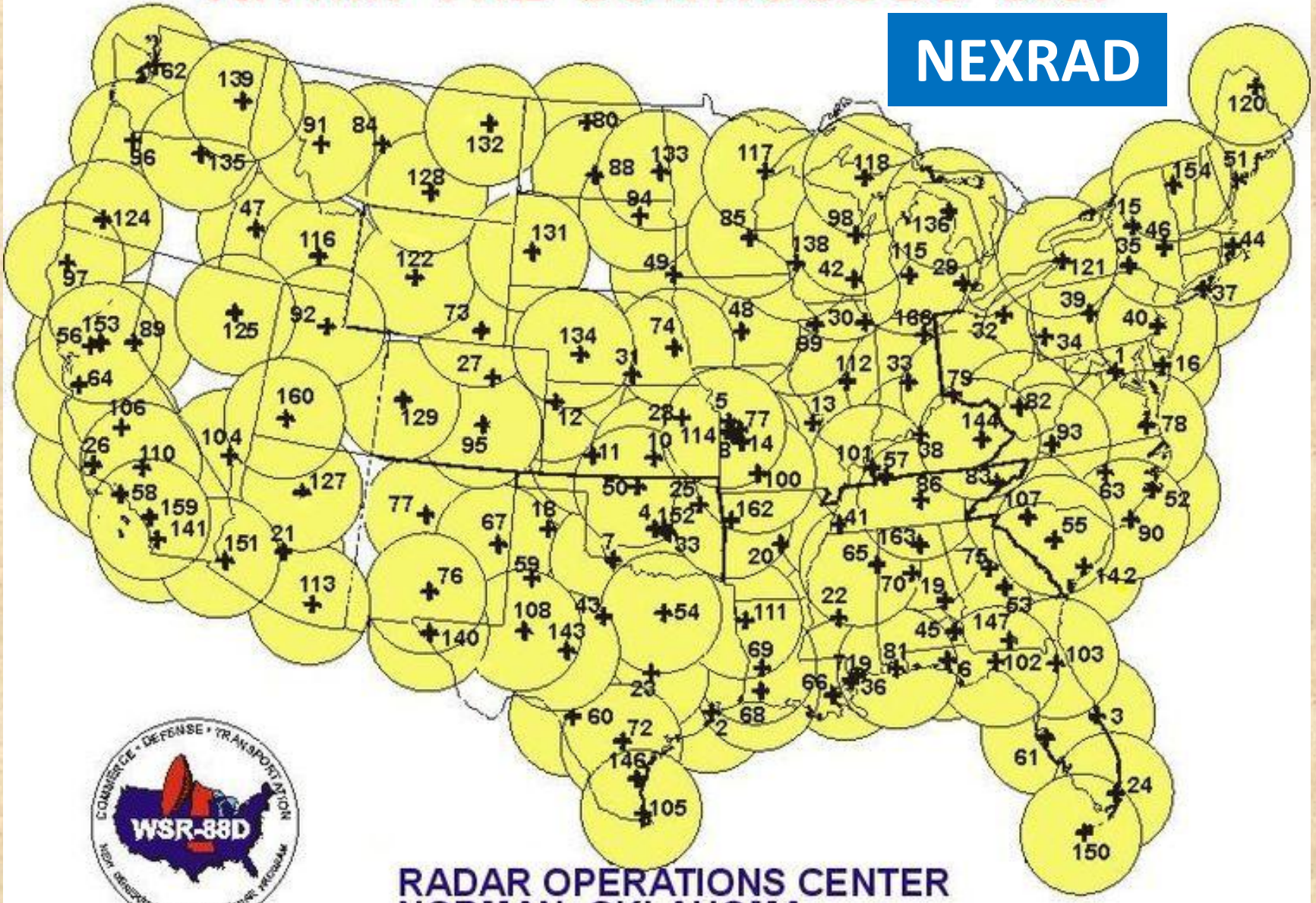
TORNADOS



SQUALL LINES

COMPLETED WSR-88D INSTALLATIONS WITHIN THE CONTIGUOUS U.S.

NEXRAD



RADAR OPERATIONS CENTER
NORMAN, OKLAHOMA

- **1979: NEXRAD Joint System Program Office (JSPO)was formed to move forward with the development and deployment of the proposed NEXRAD radar network.**
- **January 1990: Unisys was selected as the contractor, and was awarded a full-scale production contract.**
- **June 1992: The first installation of a WSR-88D for operational use in everyday forecasts was in Sterling, Virginia.**
- **August 1997: The last originally planned system of this installation campaign was installed in North Webster, Indiana.**

- **1979: NEXRAD Joint System Program Office (JSPO)was formed to move forward with the development and deployment of the proposed NEXRAD radar network.**
- ***1984: DUAL POLARIZATION BREAK POINT***
- **January 1990: Unisys was selected as the contractor, and was awarded a full-scale production contract.**
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BACK TO THE TOPIC OF DUAL POLARIZATION WEATHER RADAR

VIDEO CLIP PREPARED BY THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINSTRATION'S NATIONAL WEATHER SERVICE TO ANNOUNCE THE UPGRADE OF THE NATION'S WSR-88

THAT WEATHER SHOW

NOAA/NWS VIDEO CLIP

WHY RADAR METEOROLOGY AT OHIO STATE?

WEATHER RADAR COULD DETECT RAINFALL, BUT WAS UNABLE TO MEASURE IT VERY ACCURATELY!!

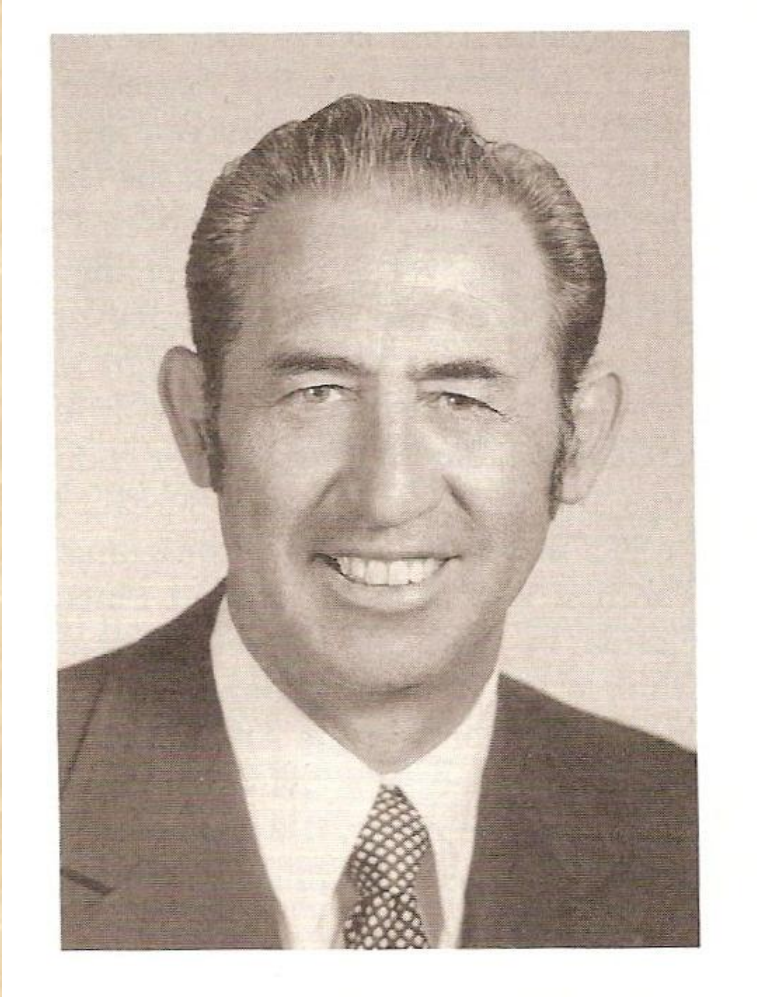
TRANSITIONING FROM IONOSPHERIC WAVE PROPAGATION TO RADAR METEOROLOGY AT OHIO STATE UNIVERSITY

- THE OSU ATMOSPHERIC SCIENCES PROGRAM
- WAINING NATIONAL INTEREST IN IONOSPHERIC WAVE PROPAGATION
- NSF EXPERIENCE
  - LEARNING ABOUT METEOROLOGY AND THE BROADER NATIONAL ATMOSPHERIC SCIENCES COMMUNITY
  - THE NEED FOR A 2ND RADAR PARAMETER TO IMPROVE RADAR MEASUREMENT OF RAINFALL AND THE DUAL WAVELENGTH APPROACH
- NEED FOR GREATER FOCUS ON METEOROLOGY AT OSU
- TAKING ON THE 2-PARAMETER CHALLENGE
- INSTITUTIONAL FLEXIBILITY
- TAKING ADVANTAGE OF GRADUATE STUDENT AND FACULTY SUPPORT PROGRAMS AT NCAR/UCAR

KEY PLAYERS LEADING TO INTEREST IN RADAR METEOROLGY

- ARTHUR WAYNICK – opportunity to serve NSF as Program Director for Aeronomy
- FRED WHITE – NSF Director of the Atmospheric Sciences Section
- EUGENE BIERLY – Program Director for Meteorology
- LOU BATTAN – University of Arizona, Radar Meteorologist
- DAVID ATLAS – AFCRL, University of Chicago, Radar Meteorologist (NCAR, NASA)

RENOWNED IN THE FIELD



LOU BATTAN
UNIVERSITY OF ARIZONA

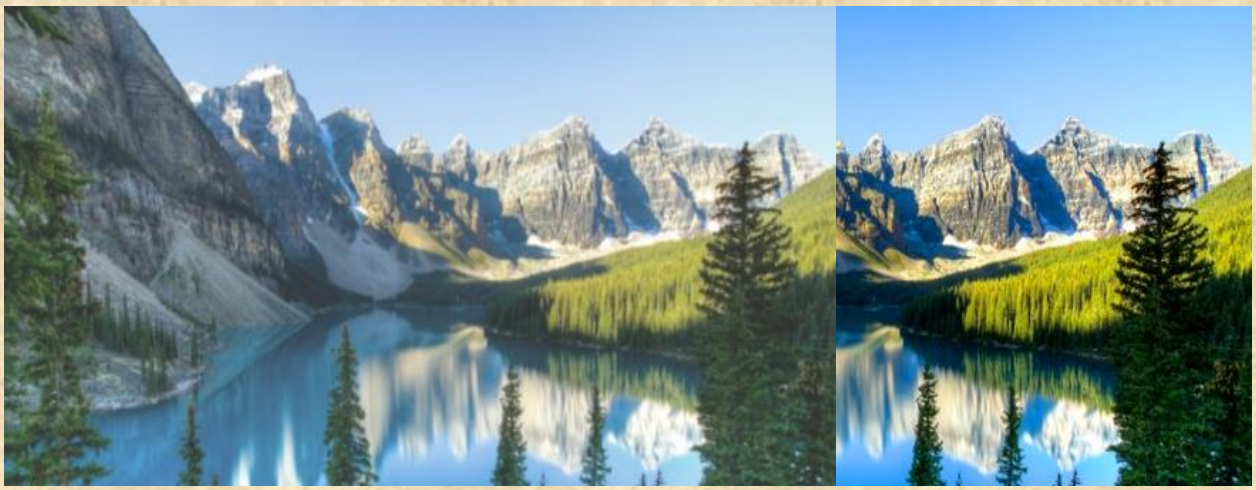
DAVE ATLAS
UNIVERSITY OF CHICAGO

WHAT IS DUAL POLARIZATION WEATHER RADAR TECHNOLOGY?

TECHNOLOGICAL MEANS OF USING ELECTRIC FIELD PROPERTIES OF ELECTROMAGNETIC RADIATION AND ITS INTERACTION WITH ATMOSPHERIC PARTICLES SUCH AS RAINDROPS, HAIL AND SNOWFALL TO OBTAIN INFORMATION ABOUT THE SPATIAL AND TEMPORAL STATE OF THESE ENTITIES AND RELATED ATMOSPHERIC PHENOMENA. NUMEROUS INSIGHTS CAN BE DERIVED FROM INTELLIGENT INTERPRETATION OF RADAR MEASUREMENTS THAT USE POLARIZATION-BASED RADAR MEASUREMENTS.

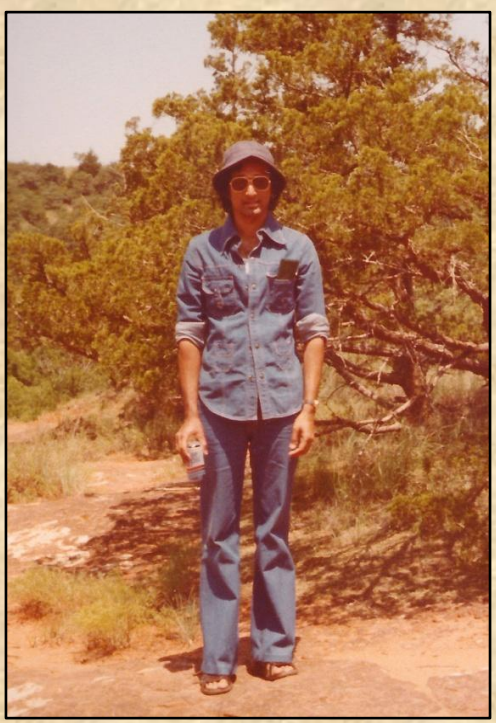
NORMAL VISION

VERTICALLY POLARIZED VISION



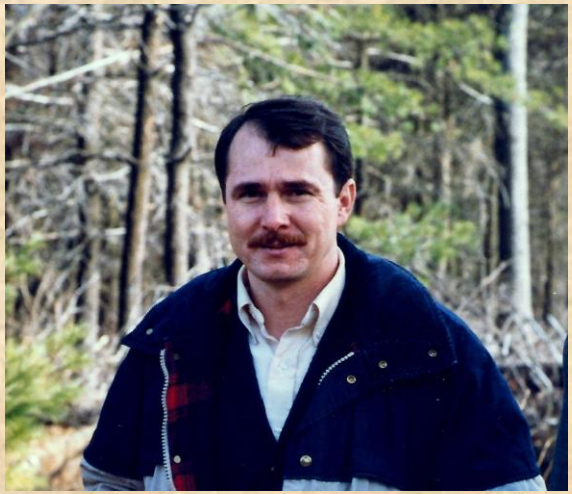
DIFFERENTIAL VISION

COLLABORATORS



V. N. BRINGI – OSU, CSU

MARTIN HALL & STEVE CHERRY, APPLETON

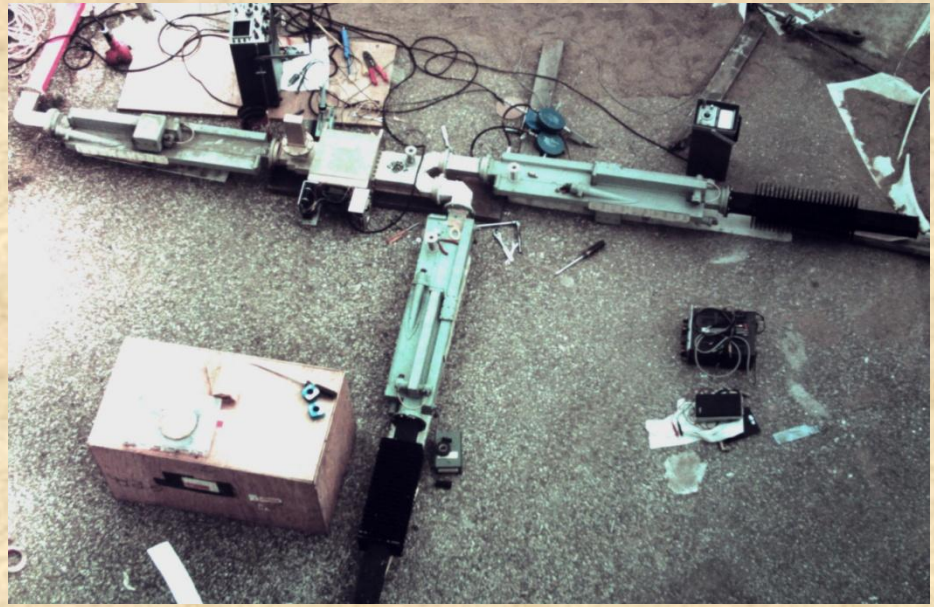


KULTEGIN AYDIN, OSU, PSU

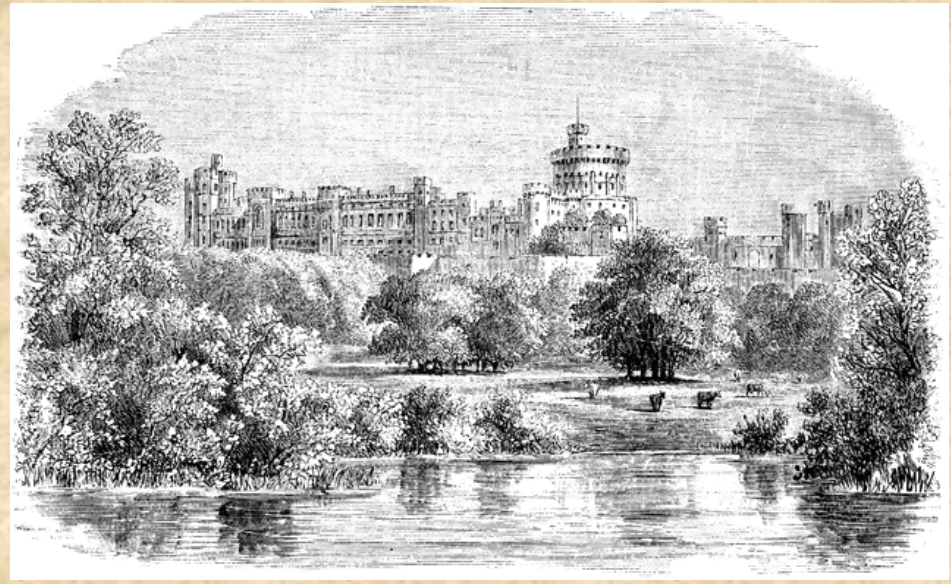
DINO GIULI, FLORENCE

EUGENIO GORGUCCI, ITALY
CNR

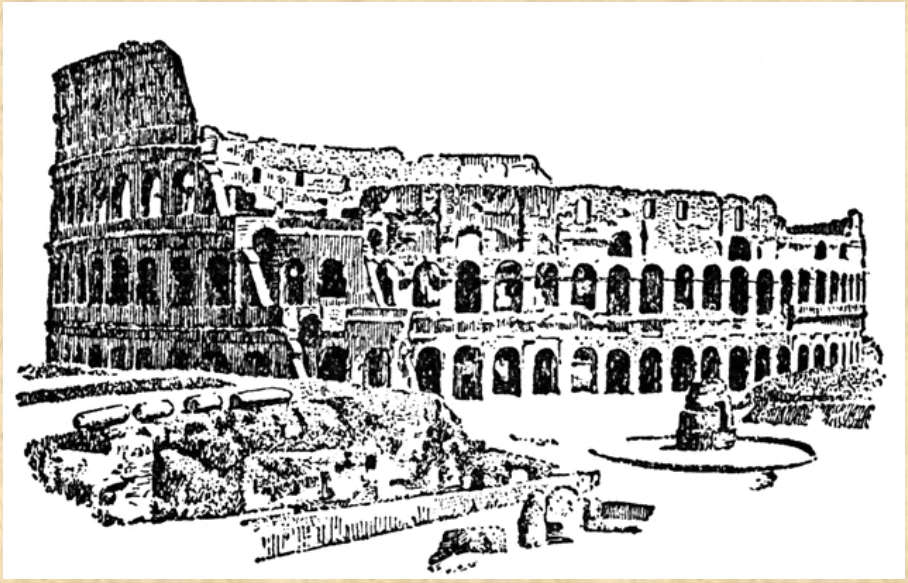
GENE MUELLER, ILLINOIS STATE WATER SURVEY
ELECTRICAL ENGINEER/RADAR METEOROLOGIST



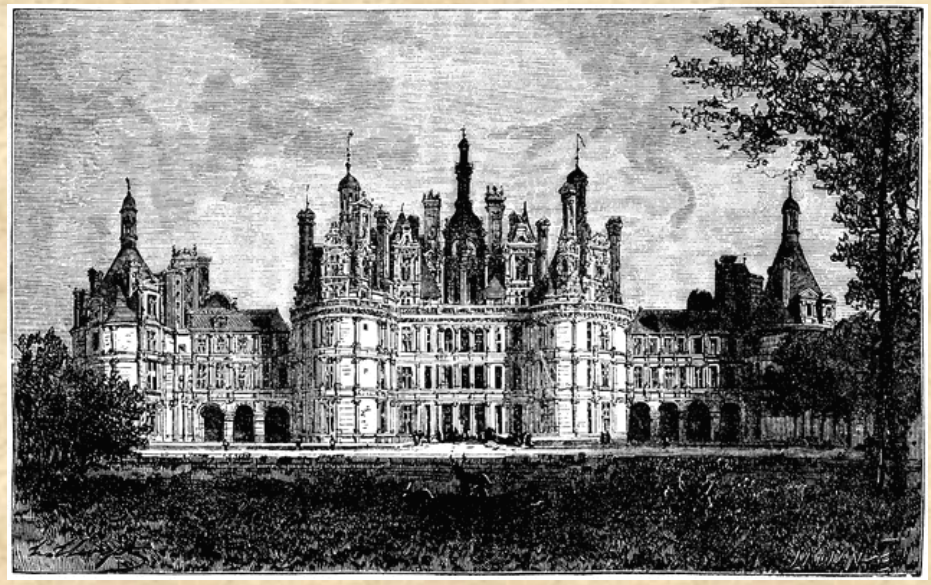
INSTALLATION OF THE FAST FERRITE SWITCH ON THE CHILL RADAR AND CALIBRATION TEST AT THE UNIVERSITY OF ILLINOIS FOOTBALL STADIUM



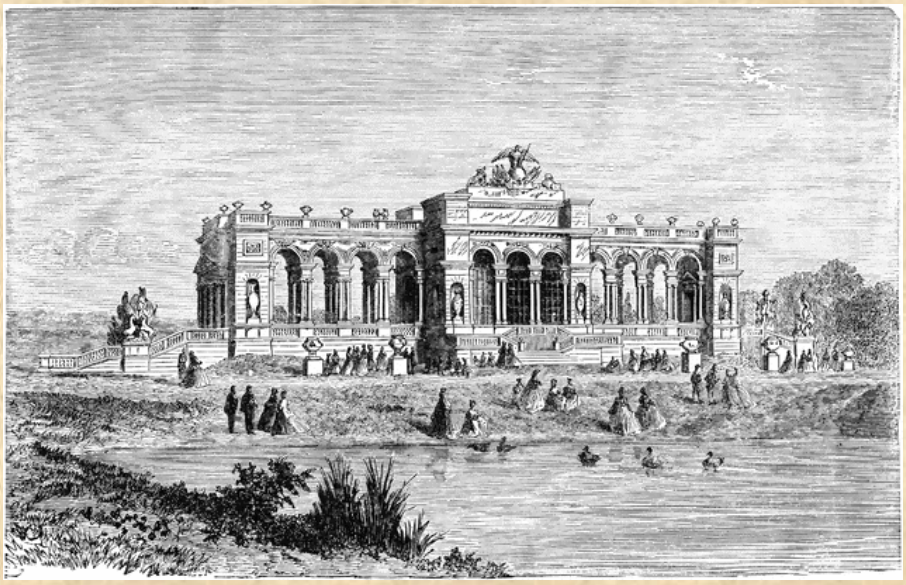
UK: WINDSOR CASTLE



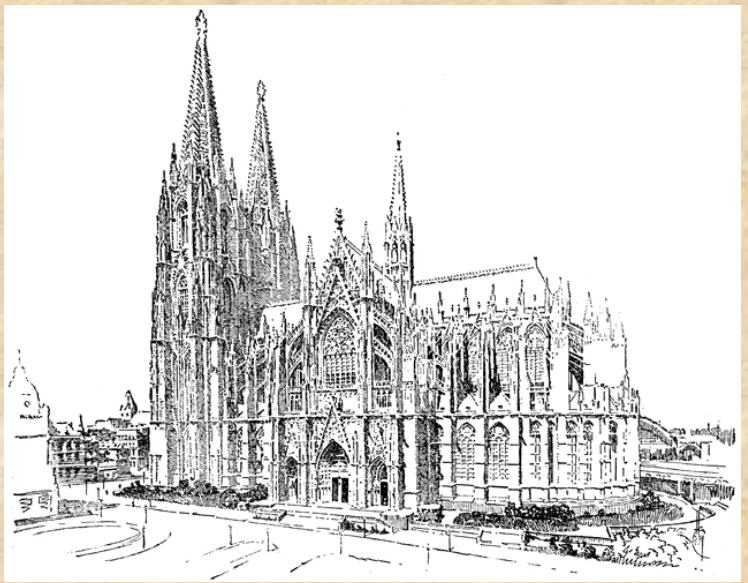
ITALY: COLOSEUM



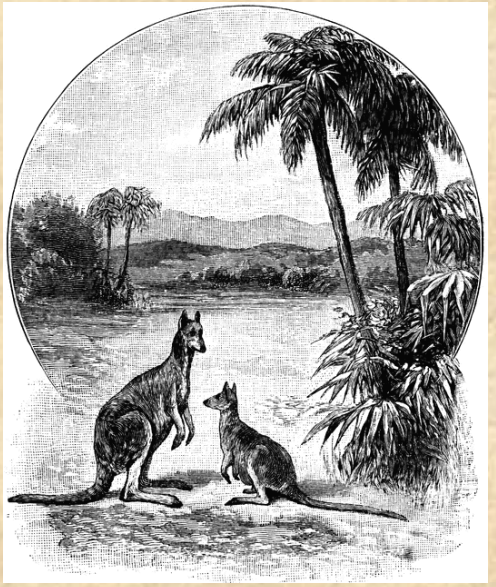
FRANCE: CHATEAU OF CHAMBORD



AUSTRIA: SCHONBRUNN



GERMANY: COLOGNE



AUSTRALIA

JAPAN

CLIP ART ATTRIBUTIONS

Source: FLOOD
Frank Beard *Bible Symbols or The Bible in Pictures* (London, England: Hertel, Jenkins & Co., 1904)
Courtesy the private collection of Roy Winkelman

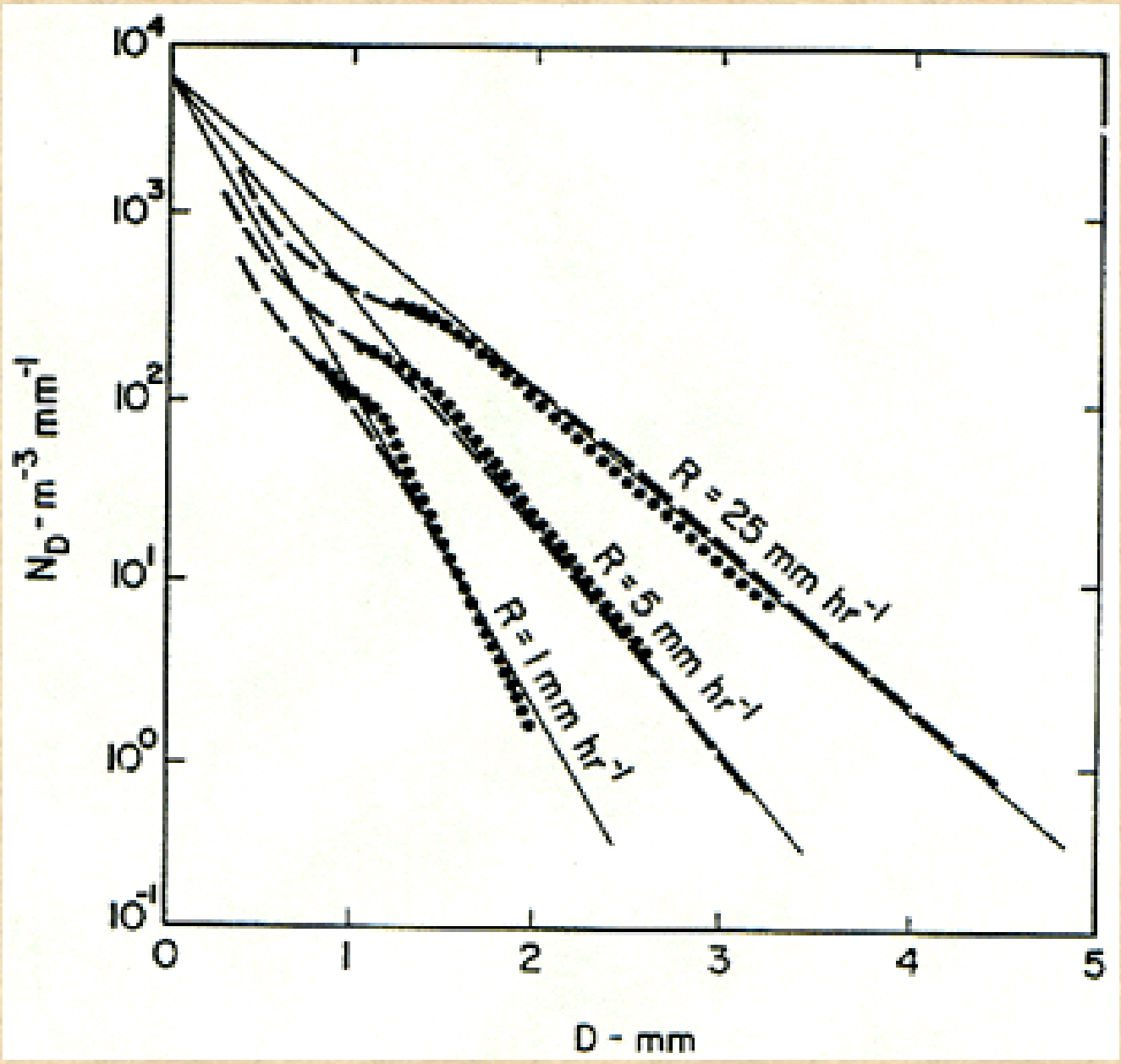
Source: TORNADO
Edwin J. Houston, *The Elements of Physical Geography, for the use of Schools, Academies, and Colleges.* (Philadelphia: Eldredge & Brother, 1891) 150
Courtesy the private collection of Roy Winkelman

Source: THUNDERSTORM
Rollin D. Salisbury *American Science Series - Advanced Course: Physiography* (New York, NY: Henry Holt and Company, 1919)
Courtesy the private collection of Roy Winkelman

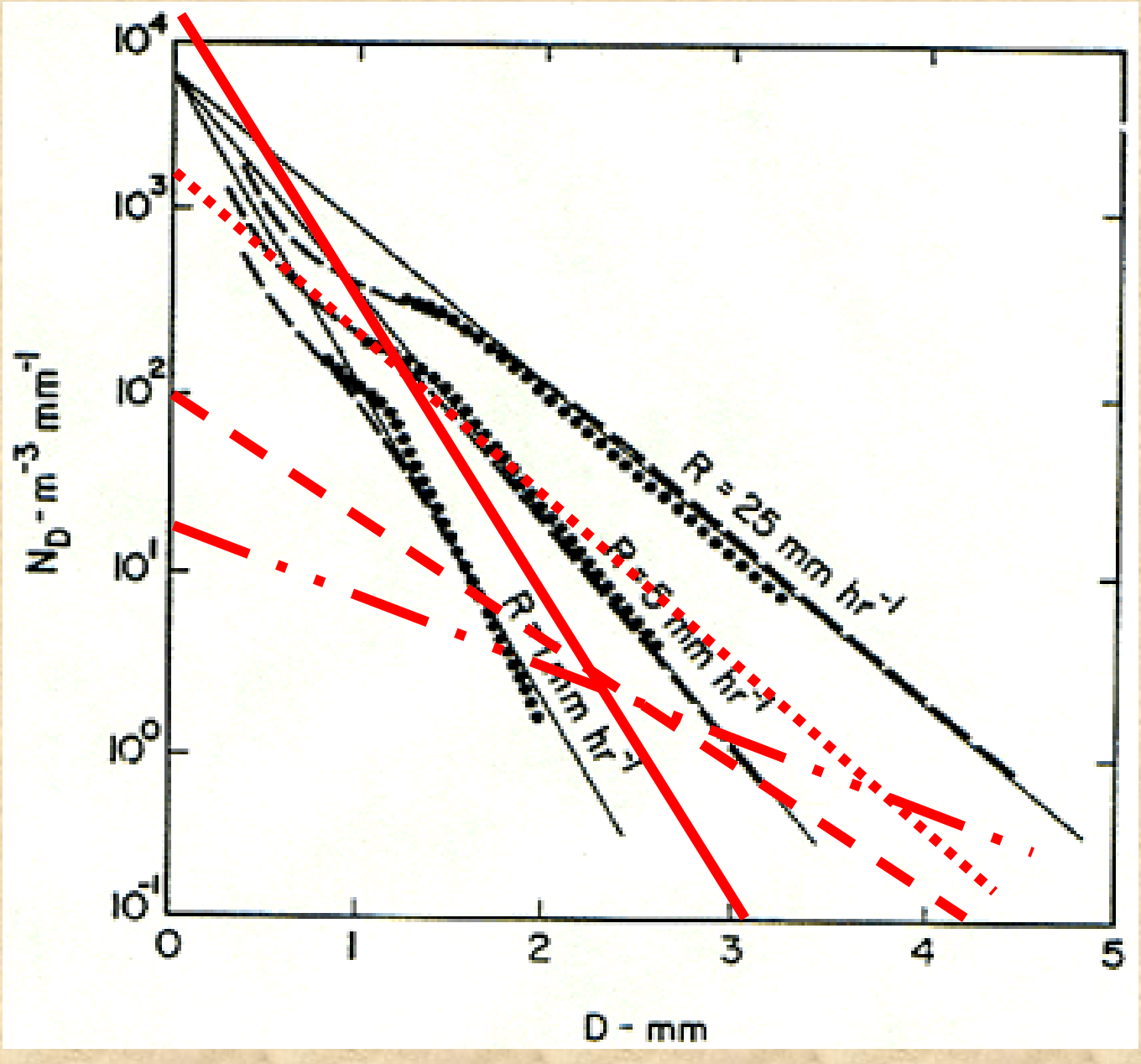
Source: LINE SQUALL
Finley, John H. *Nelson's Perpetual Loose-Leaf Encyclopedia* (New York City: Thomas Nelson and Sons, 1917) 11:393b
Courtesy the private collection of Roy Winkelman

RAINFALL CONSISTS OF RAINDROPS, CHARACTERIZED BY

- DIFFERENT DROP SIZES
- DIFFERENT FALL SPEEDS
- DIFFERENT SHAPES
- DIFFERENT BACKSCATTERING CROSS SECTIONS

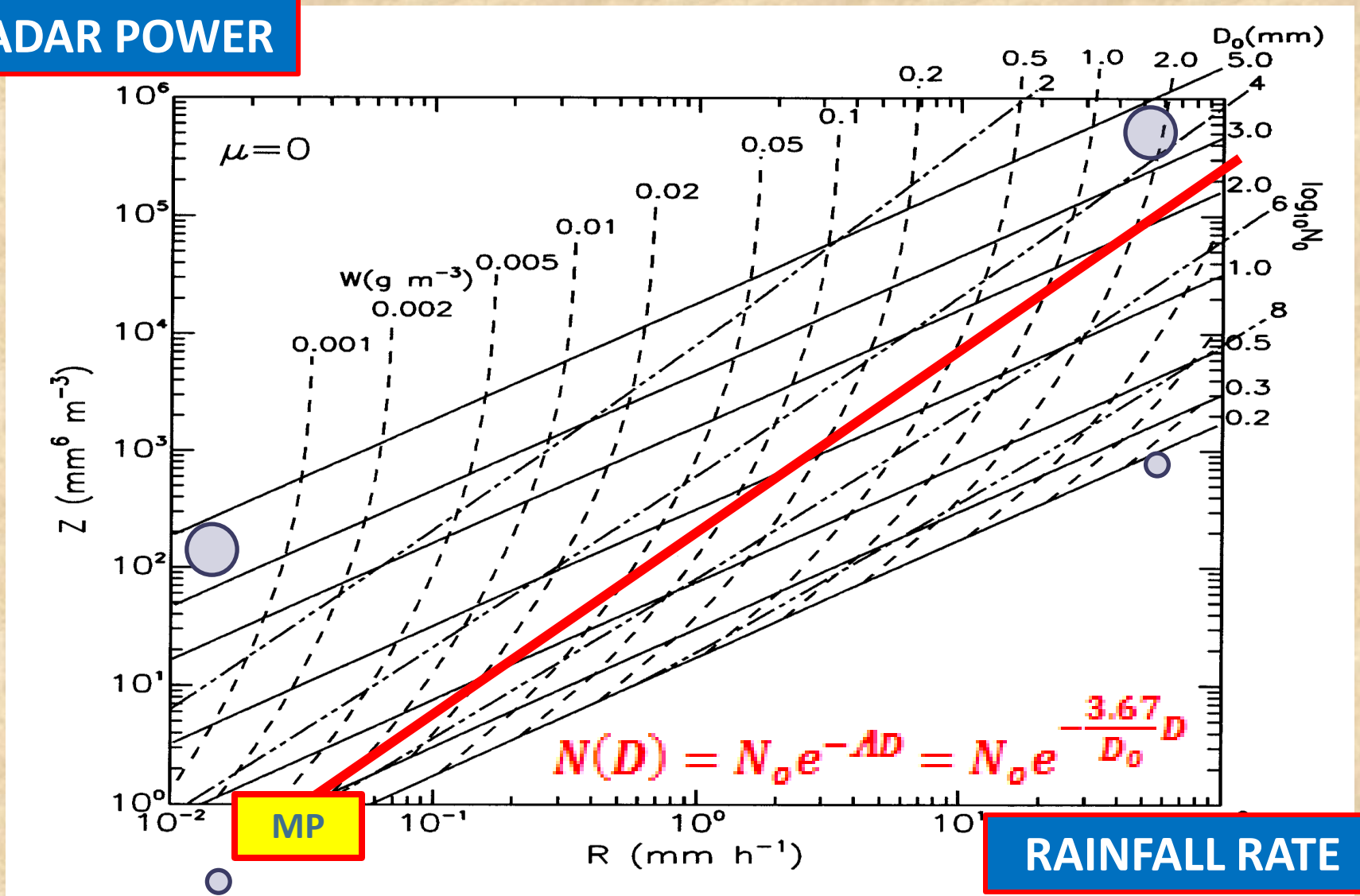


MARSHALL – PALMER (1948) EXPONENTIAL DISTRIBUTIONS

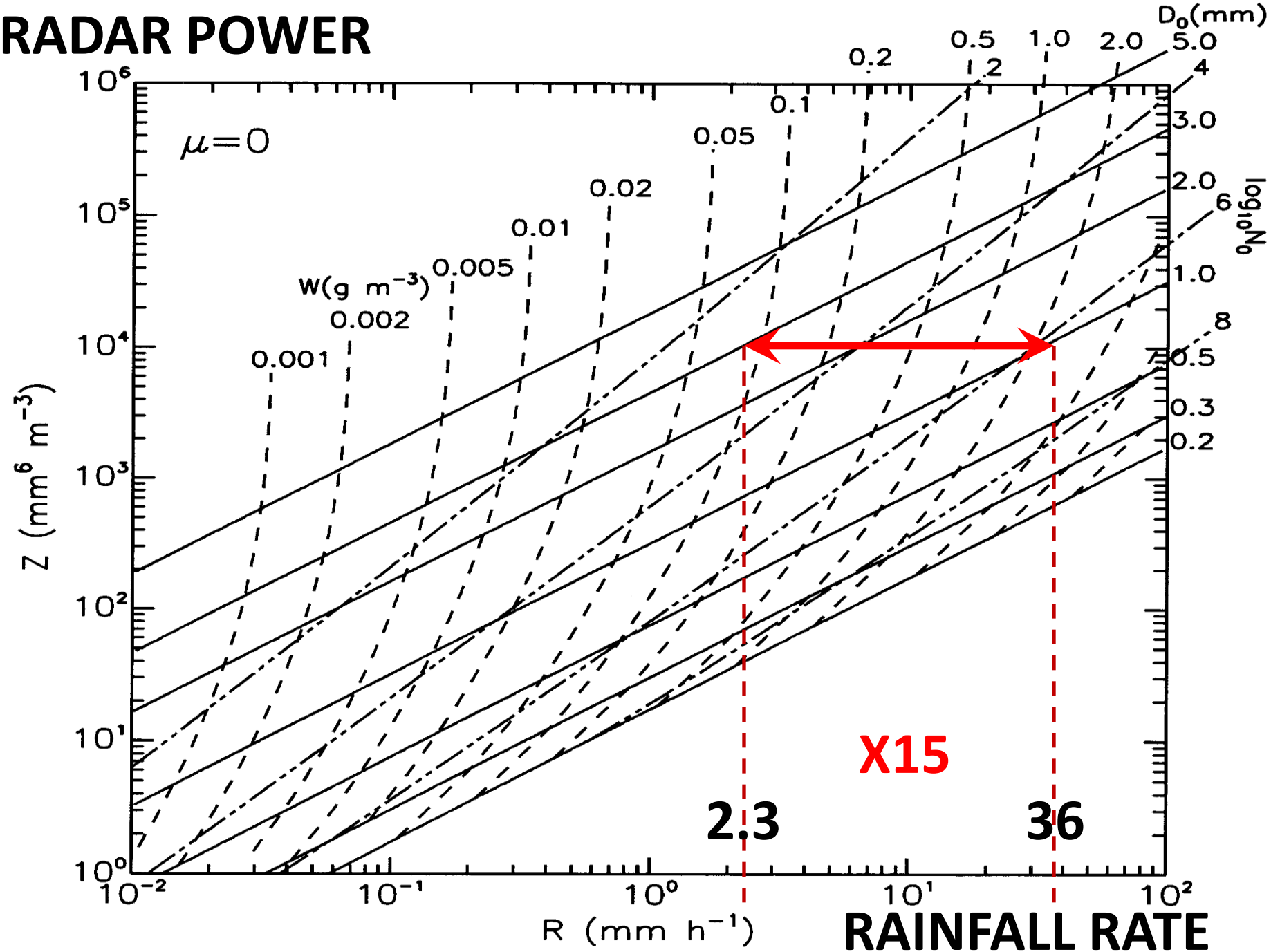


OTHER EXPONENTIAL DISTRIBUTIONS

THE RAIN PARAMETER DIAGRAM OF ATLAS, CHEMELA AND ULBRICH

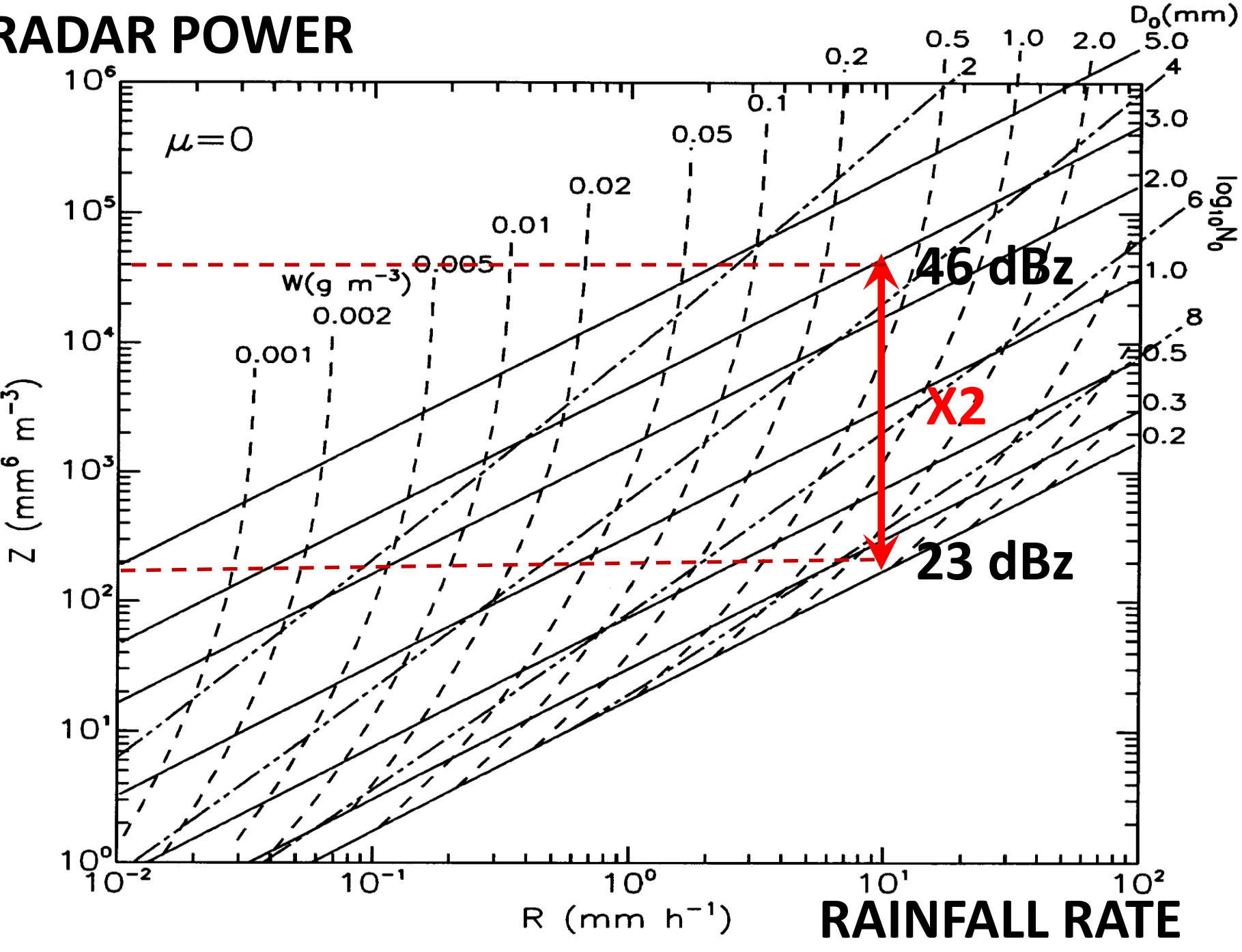


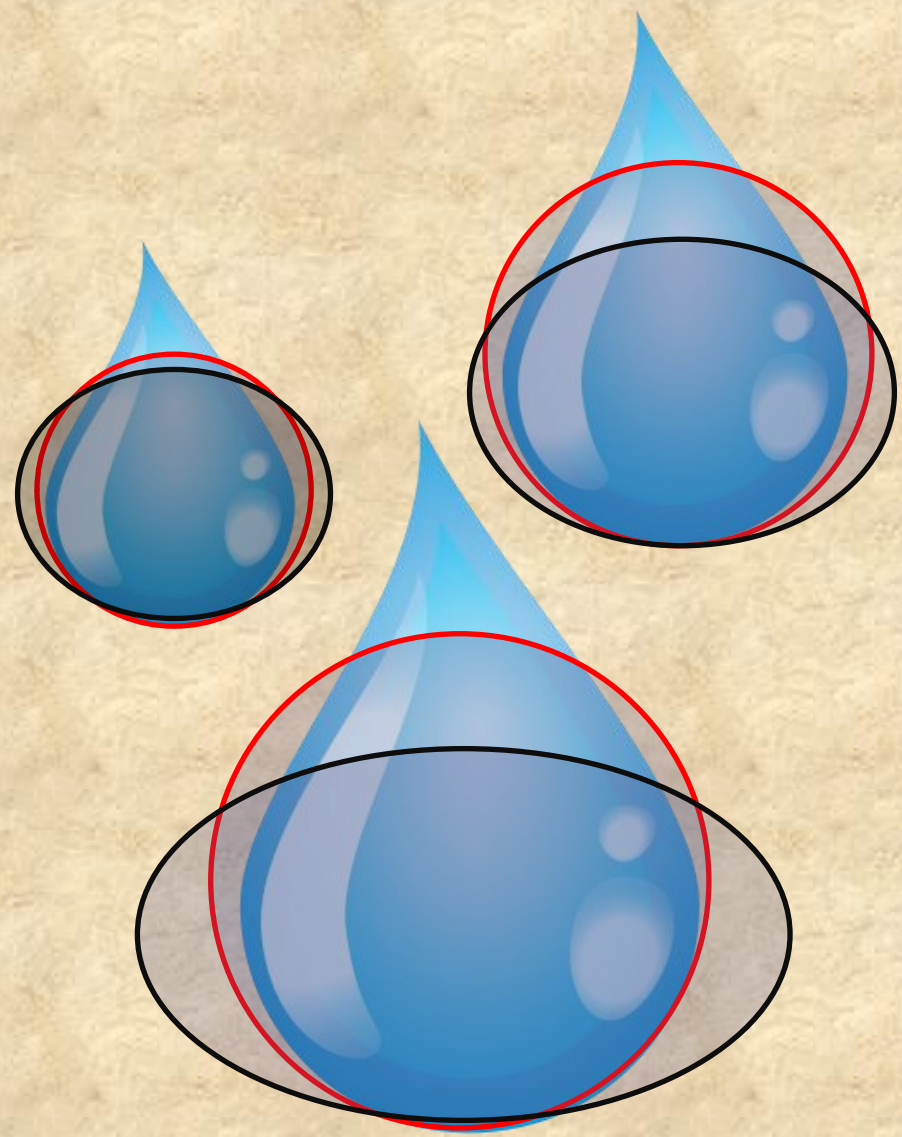
RADAR POWER



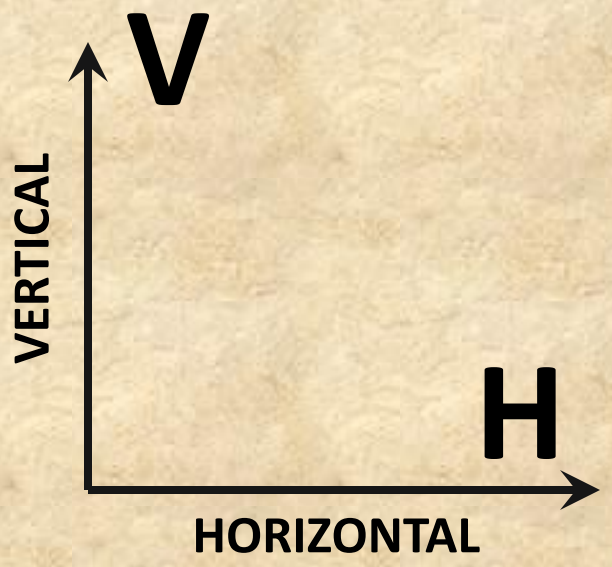
D_0(mm)
5.0
4
3.0
2.0
6
1.0
8
0.5
0.3
0.2
$\log_{10}N_0$
0.2
0.5
1.0
2.0
.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
W(g m^{-3})
$\mu=0$
Z (mm^6 m^{-3})
R (mm h^{-1})
X15
2.3
36
RAINFALL RATE

RADAR POWER

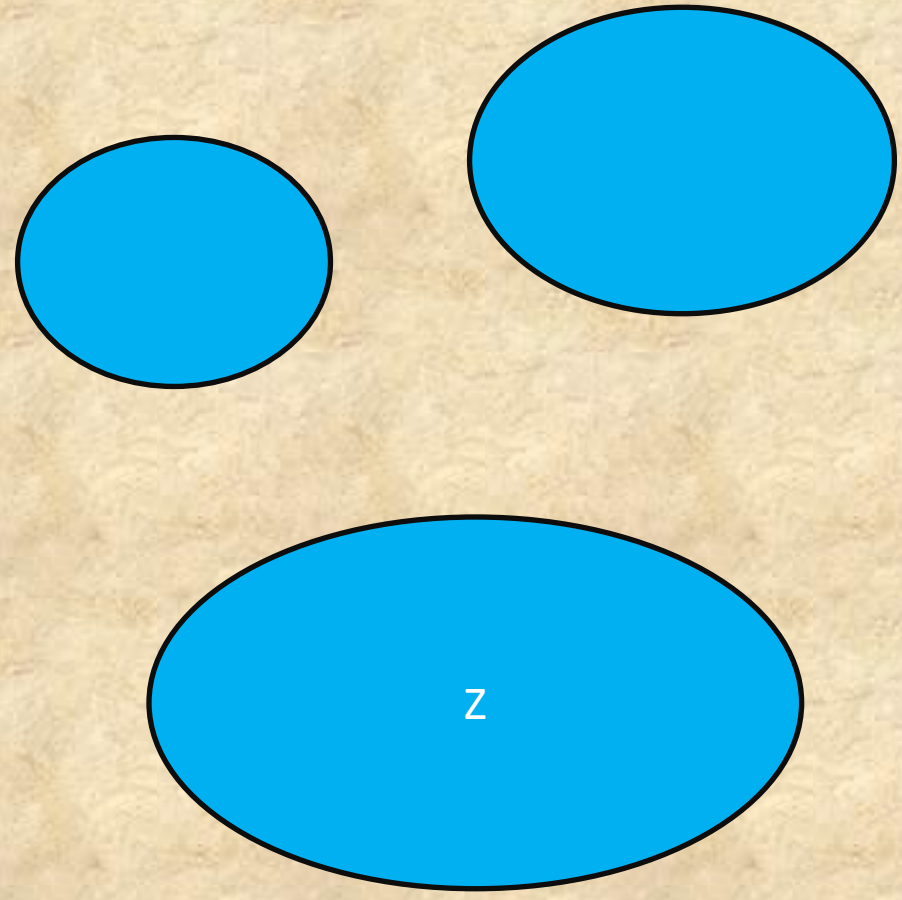

D_0(mm)
0.2
0.5
1.0
2.0
5.0
.2
4
3.0
2.0
1.0
0.5
0.3
0.2
μ=0
0.1
0.05
0.02
0.01
0.005
W(g m^{-3})
0.002
0.001
46 dBz
X2
23 dBz
$\log_{10}N_0$
6
8
10^6
10^5
10^4
10^3
10^2
10^1
10^0
Z (mm^6 m^{-3})
10^{-2}
10^{-1}
10^0
10^1
10^2
R (mm h^{-1})
RAINFALL RATE

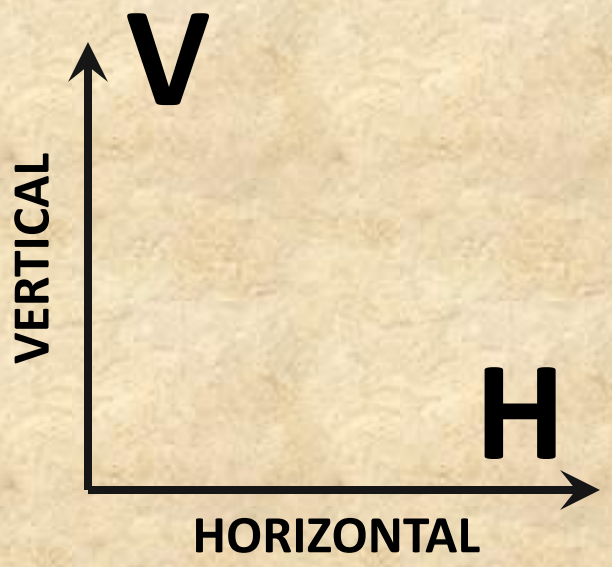


WHICH SHAPES BEST REPRESENT THE ACTUAL SHAPES OF RAINDROPS?

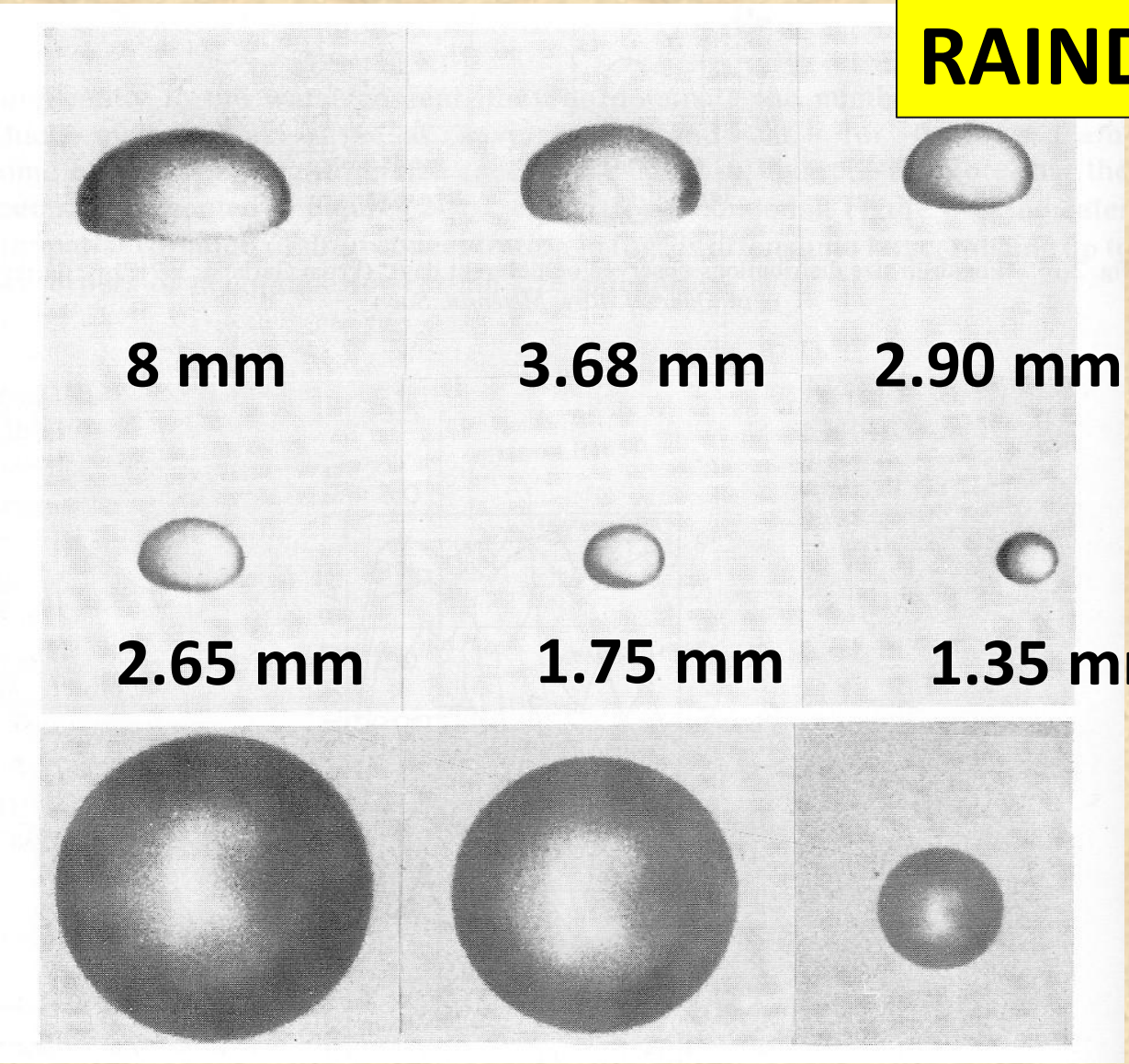


THE OBLATE SPHEROID THAT LOOKS LIKE AN EGG FROM ANY SIDE

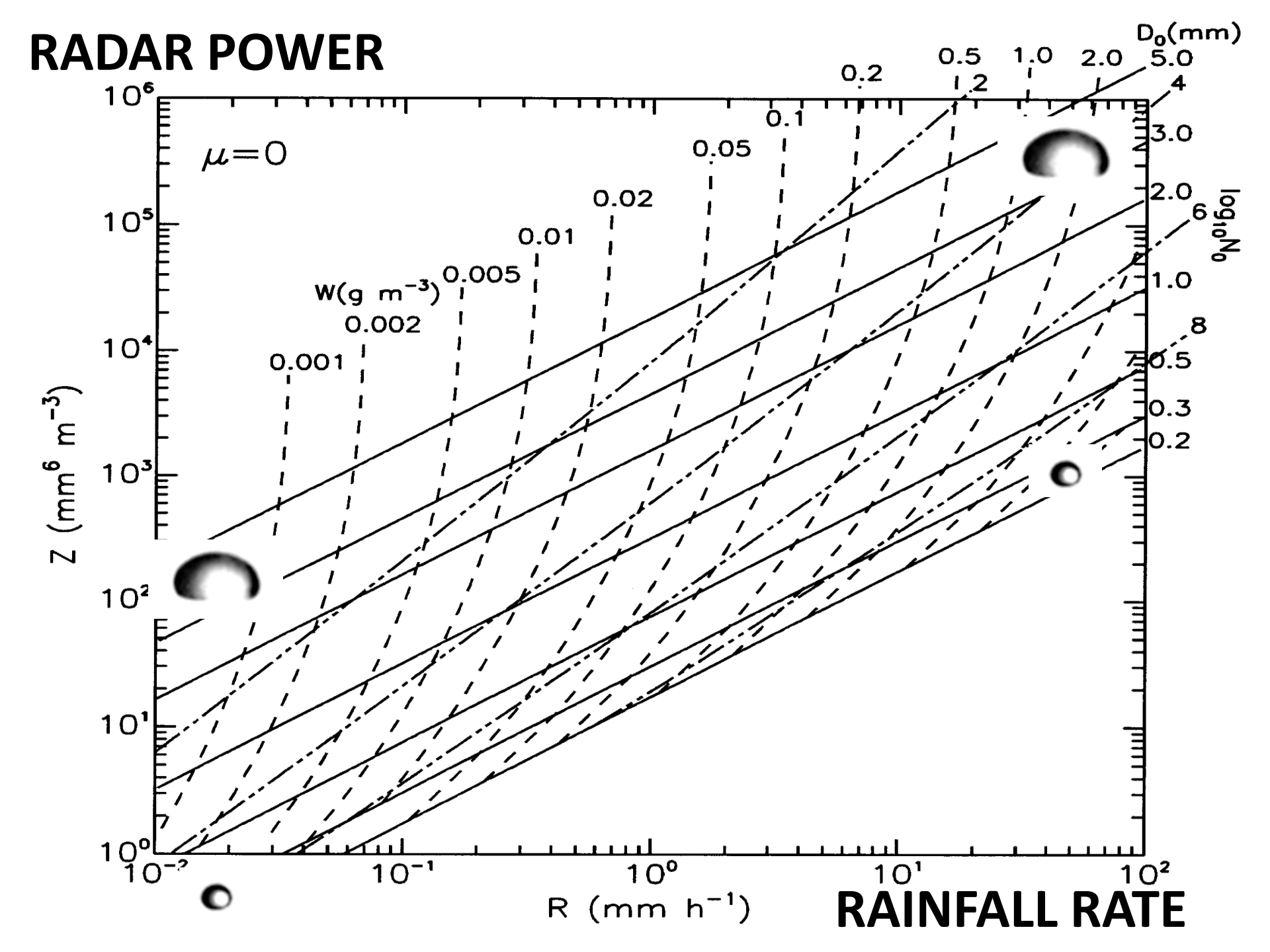


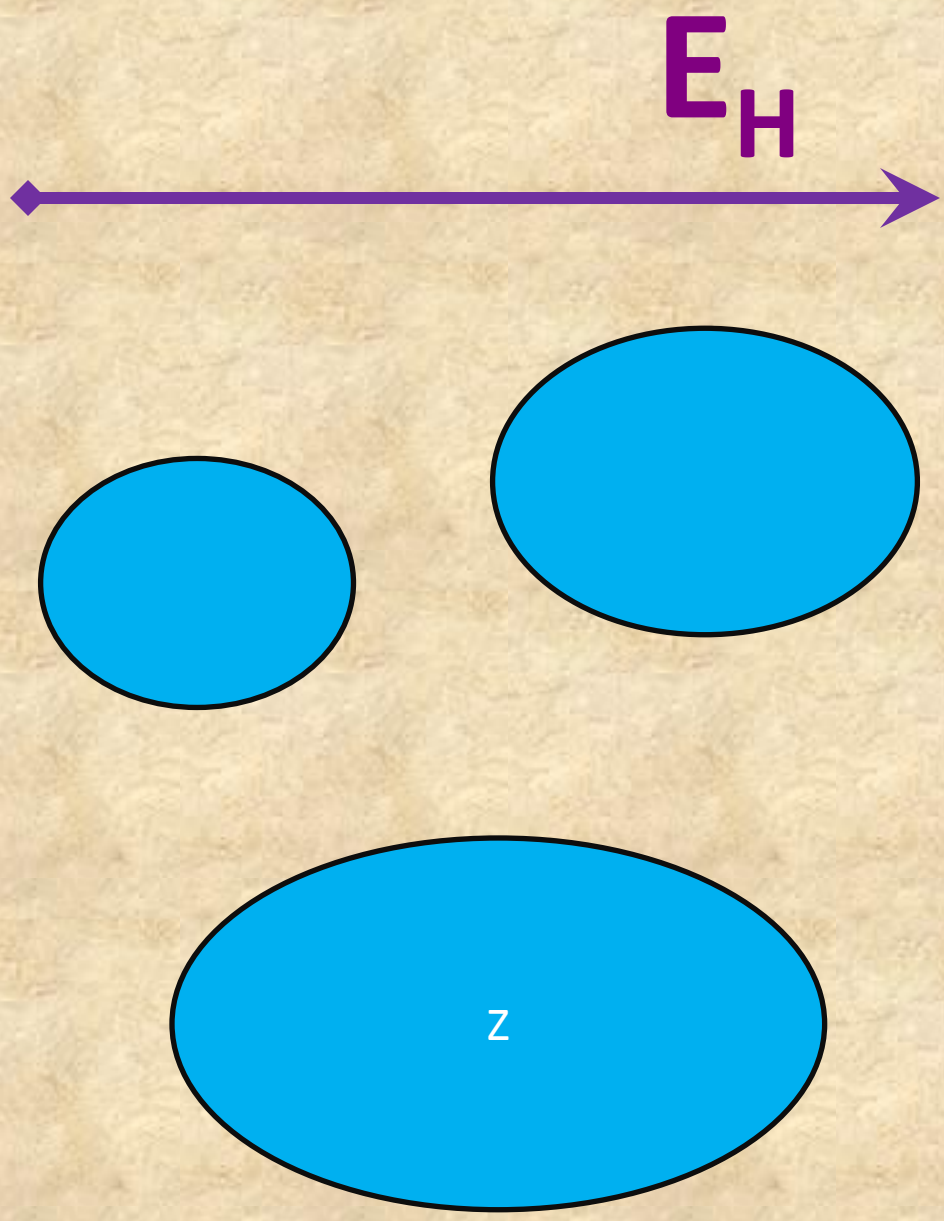


RAINDROP SHAPES

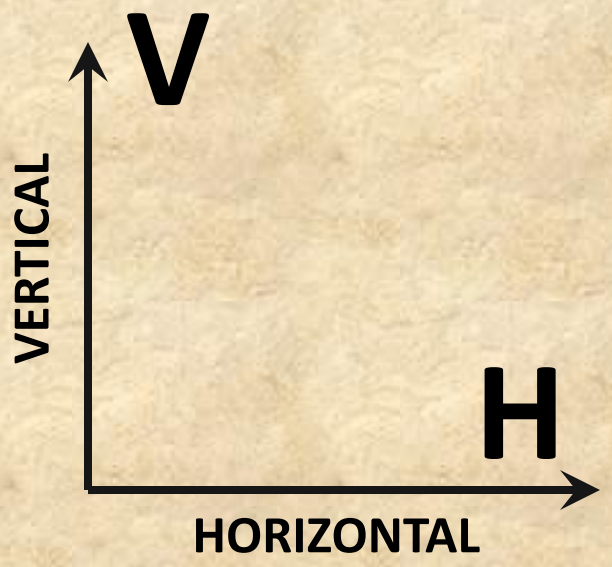


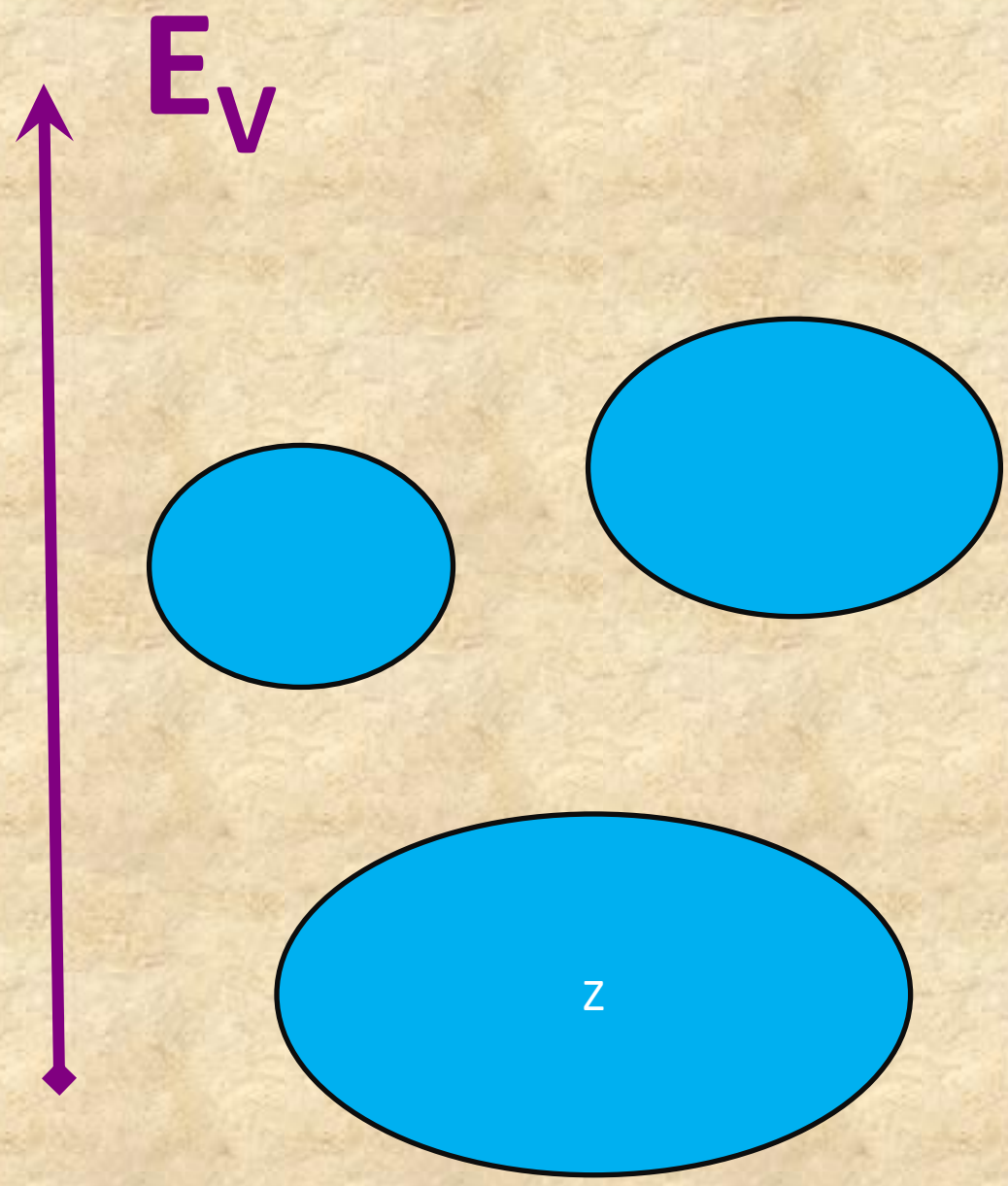
Pruppacher and Klett (1978): Microphysics of Clouds and Precipitation


RADAR POWER
RAINFALL RATE
$\mu=0$
D_0(mm)
0.2
0.5
1.0
2.0
5.0
0.1
0.05
0.02
0.01
0.005
0.002
0.001
W(g m^{-3})
10^6
10^5
10^4
10^3
10^2
10^1
10^0
Z (mm^6 m^{-3})
10^{-2}
10^{-1}
10^0
10^1
10^2
R (mm h^{-1})
4
3.0
2.0
6
1.0
8
0.5
0.3
0.2
$\log_{10}N_0$

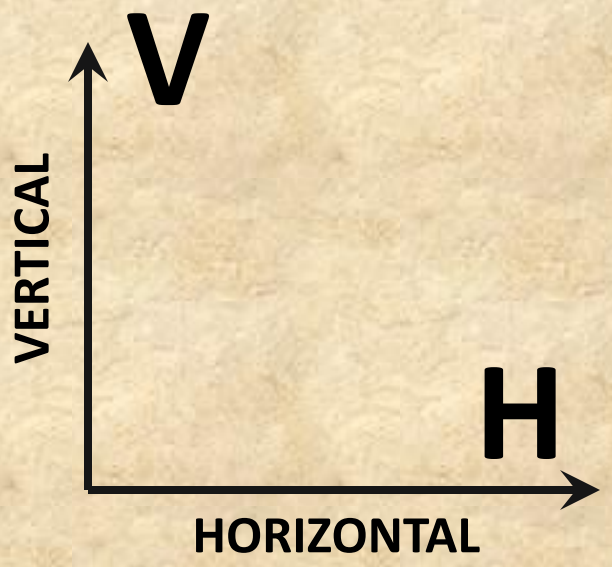


WHAT HAPPENS WHEN A RADAR EMPLOYS HORIZONTAL POLARIZATION?





WHAT HAPPENS WHEN A RADAR EMPLOYS VERTICAL POLARIZATION?



GOVERNING EQUATIONS

- **RAINFALL RATE**

$$R \propto \int_0^{D_{max}} v(D) D^3 N_0 e^{-\frac{3.67}{D_0} D} dD$$

FALL SPEED

VOLUME

NUMBER OF DROPS

GOVERNING EQUATIONS

- **REFLECTIVITY FACTOR – SPHERICAL DROPS**

$$Z \propto \int_0^{D_{max}} N_o e^{-\frac{3.67}{D_o}D} \sigma_o dD$$

- **REFLECTIVITY FACTOR AT HORIZONTAL AND VERTICAL POLARIZATIONS – ACTUAL DROPS**

$$Z_{H,V} \propto \int_0^{D_{max}} N_o e^{-\frac{3.67}{D_o}D} \sigma_{H,V} dD$$

- **DIFFERENTIAL REFLECTIVITY**

$$Z_{DR} = 10log\left[\frac{Z_H}{Z_V}\right] = 10log\left[\frac{\int_0^{D_{max}} \cancel{N_o} e^{-\frac{3.67}{D_o}D} \sigma_H dD}{\int_0^{D_{max}} \cancel{N_o} e^{-\frac{3.67}{D_o}D} \sigma_V dD}\right]$$

JANUARY 1976

Potential Use of Radar Differential Reflectivity Measurements at Orthogonal Polarizations for Measuring Precipitation

T. A. SELIGA AND V. N. BRINGI

Atmospheric Sciences Program and Department of Electrical Engineering, The Ohio State University, Columbus 43210

(Manuscript received 27 December 1974, in revised form 10 October 1975)

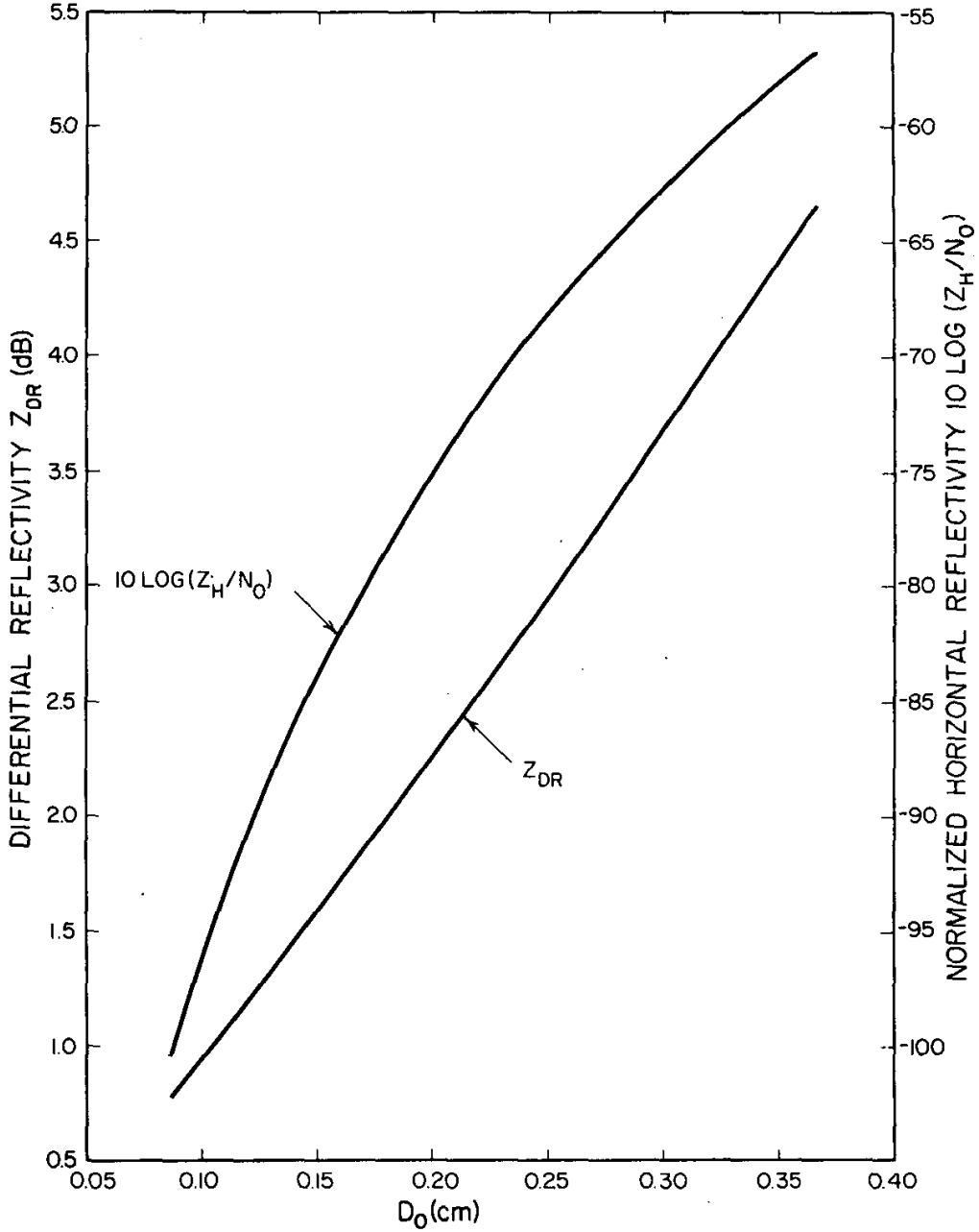


FIG. 2. Variations of Z_{DR} and normalized horizontal reflectivity 10 log (Z_H/N_0) with D_0.

THE FIRST QUANTITATIVE APPLICATION OF WEATHER RADAR POLARIZATION MEASUREMENTS

BASIC THEORETICAL AND EXPERIMENTAL DEVELOPMENTS

Seliga, T.A. and V.N. Bringi, 1976: Potential Use of Radar Differential Reflectivity Measurements at Orthogonal Polarizations for Measuring Precipitation, J. Appl. Meteor., 15, 69-76.	Z_{DR} CONCEPT AND METHODS OF MEASUREMENT
Bringi, V. N. and T. A. Seliga, 1977: Scattering from Non-spherical Hydrometeors, Annales des Telecomm., 32, Nos. 11-12, 392-397.	APPLICATIONS TO HYDROMETEORS
Seliga, T. A. and V. N. Bringi, 1978: Differential Reflectivity and Differential Phase Shift: Applications in Radar Meteorology, Radio Science, 13, 271-275..	INTRODUCTION OF DIFFERENTIAL PHASE SHIFT AS A RADAR PARAMETER & Z_{DR} OF LARGE HAIL
Seliga, T. A., V. N. Bringi and H. H. Al-Khatib, 1979: Differential Reflectivity Measurements in Rain: First Experiments, IEEE Trans. Geosci. Elect., GE-17, No. 4, 240-244.	VALIDATION OF Z_{DR} AS A VIABLE RADAR PARAMETER

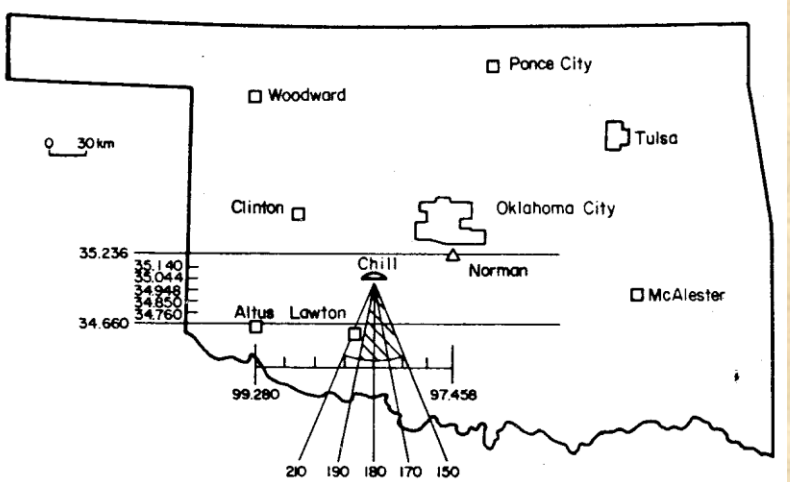
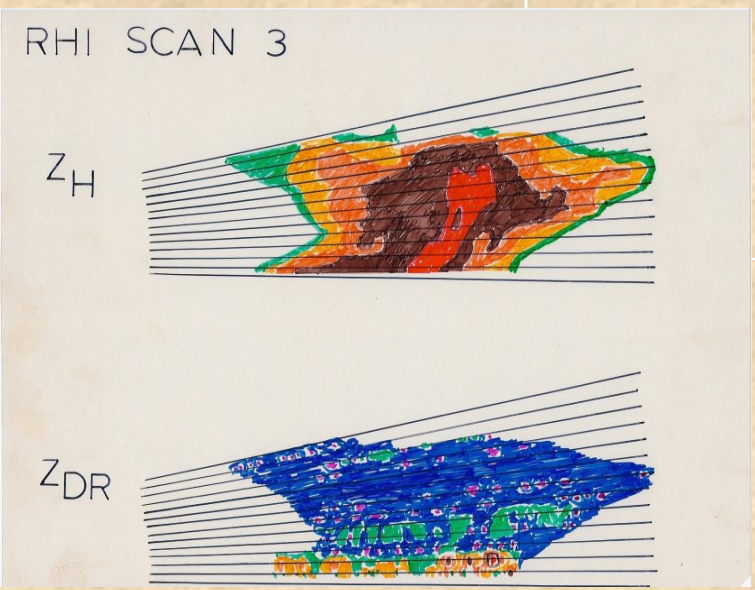
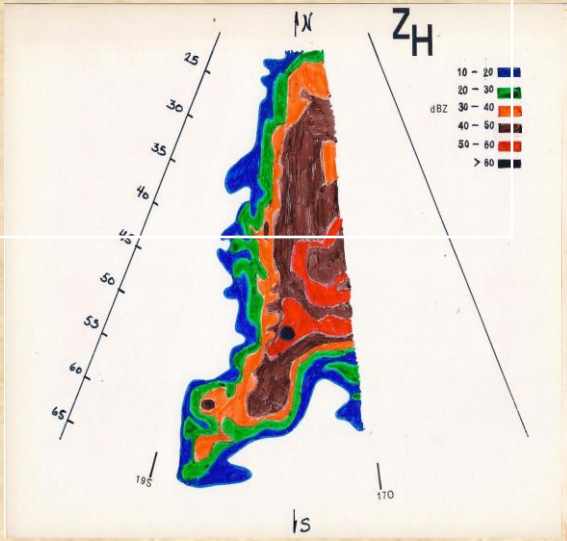
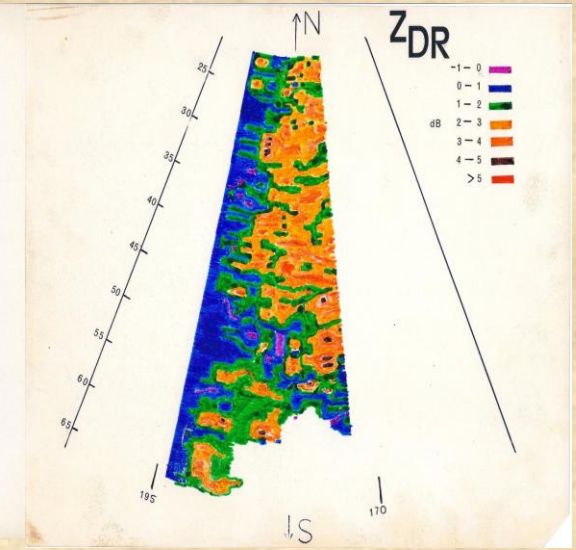


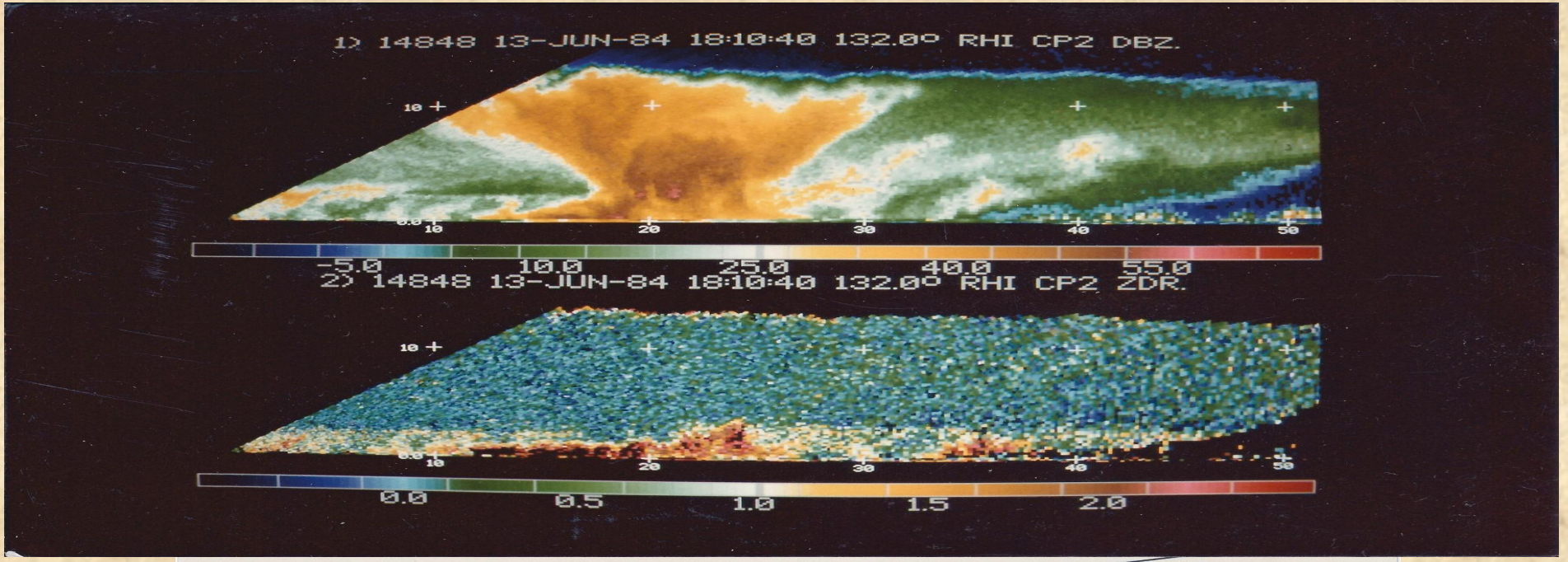
Figure 2. 2 May 1979, Chill operating mode for PPI scans (170-220°) from 23:16:44 to 23:32:63 CST

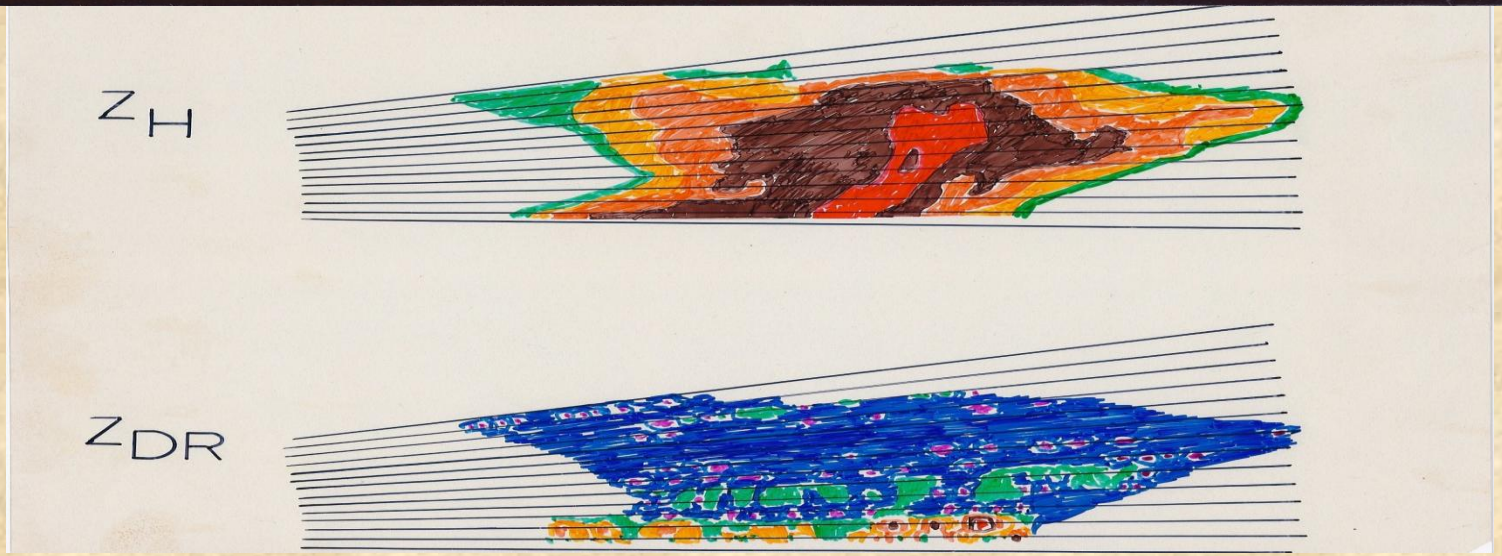






SLOW SWITCHING CHILL RADAR PPI SCANS OBSERVING A HAIL STORM IN SOUTHERN OKLAHOMA ON MAY 2, 1979



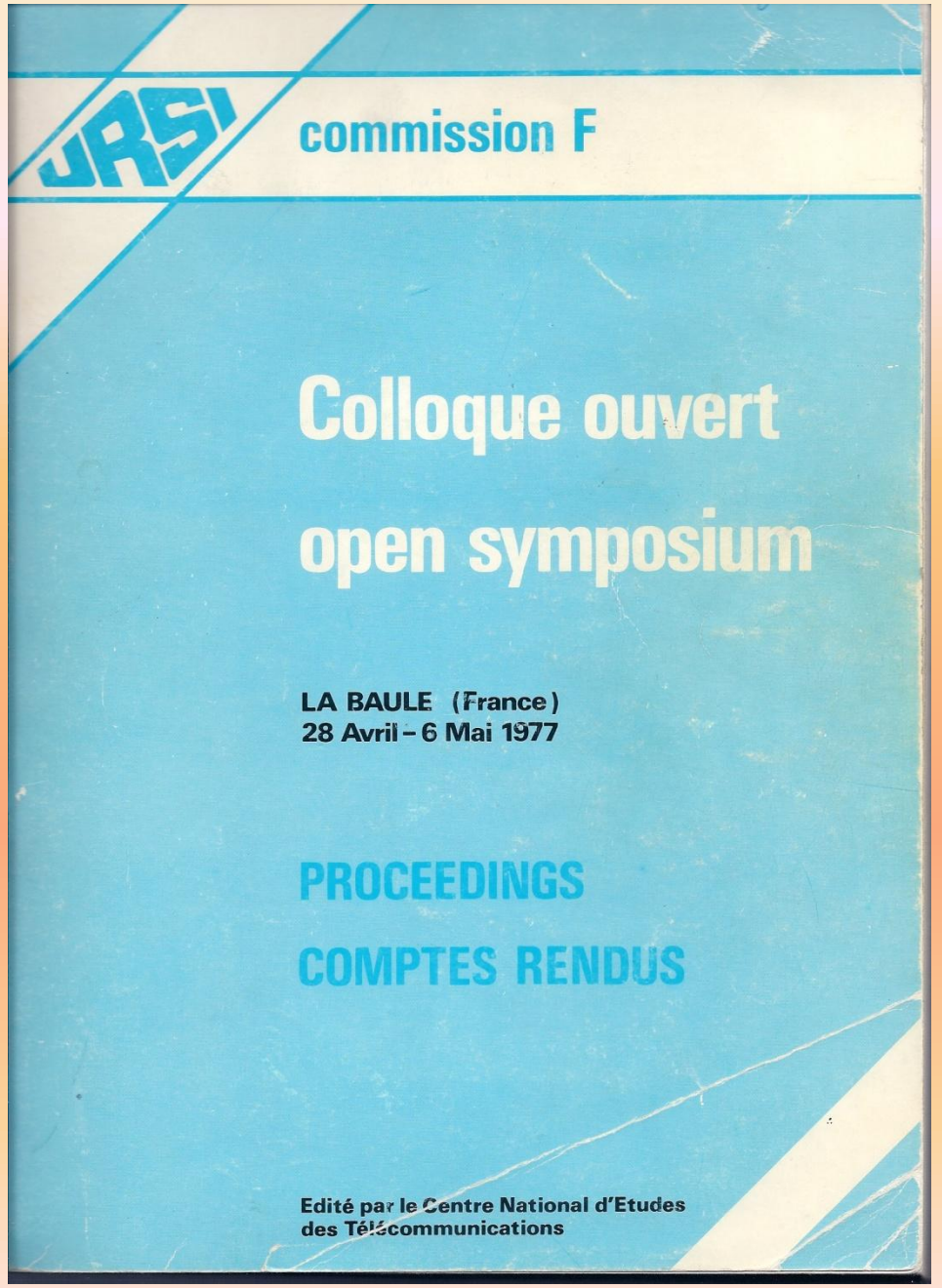


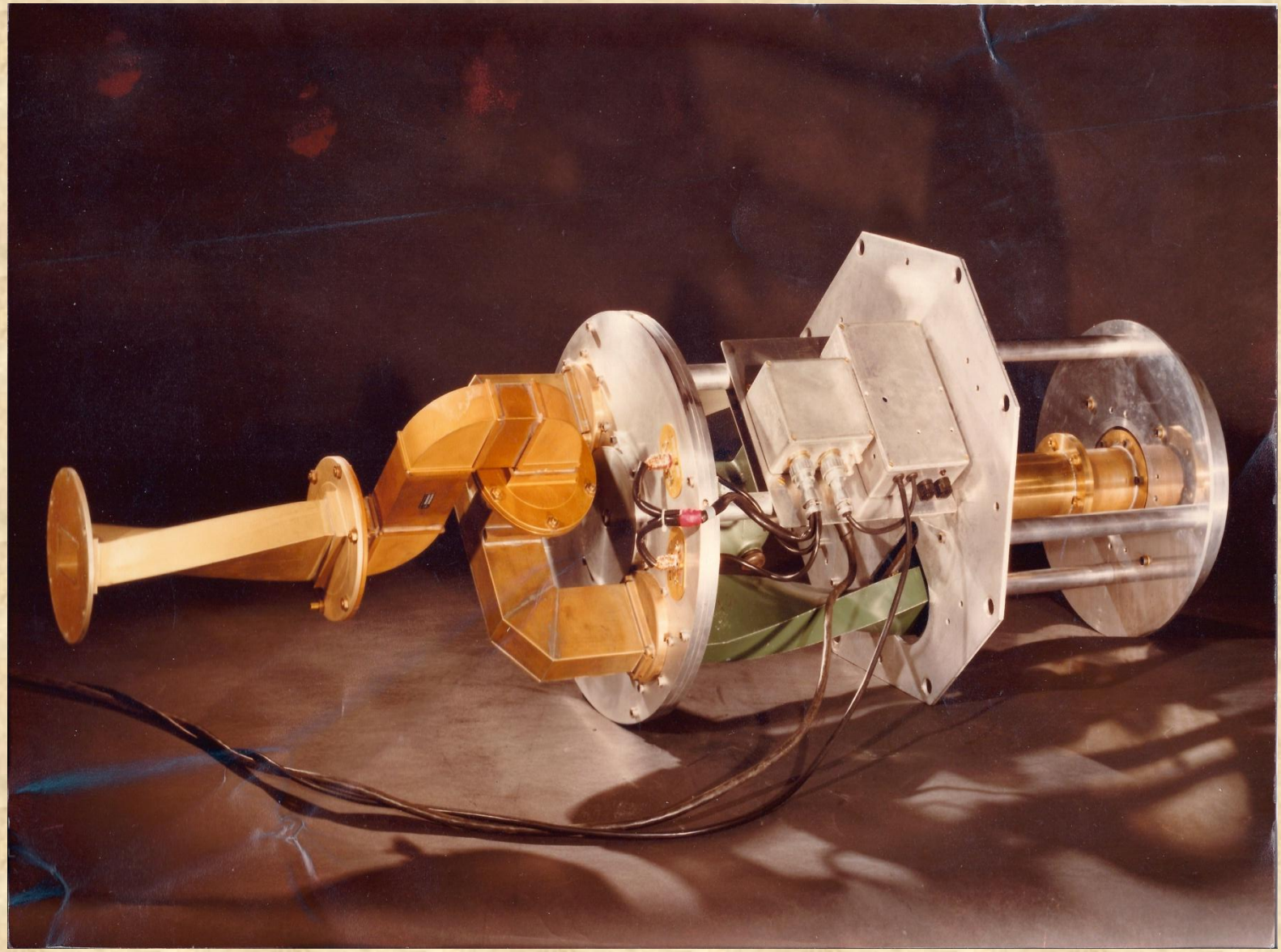
COMPARING HAIL STORM RHI SCANS WITH THE SLOW SWITCHING CHILL RADAR IN SOUTHERN OKLAHOMA ON MAY 2, 1979 AND THE FAST SWITCHING CP-2 RADAR IN COLORADOON JUNE 14, 1984

ALL KINDS OF THINGS HAPPEN AT SCIENTIFIC MEETINGS

APPLETON LABORATORY COLLABORATION

MARTIN HALL & STEVE CHERRY

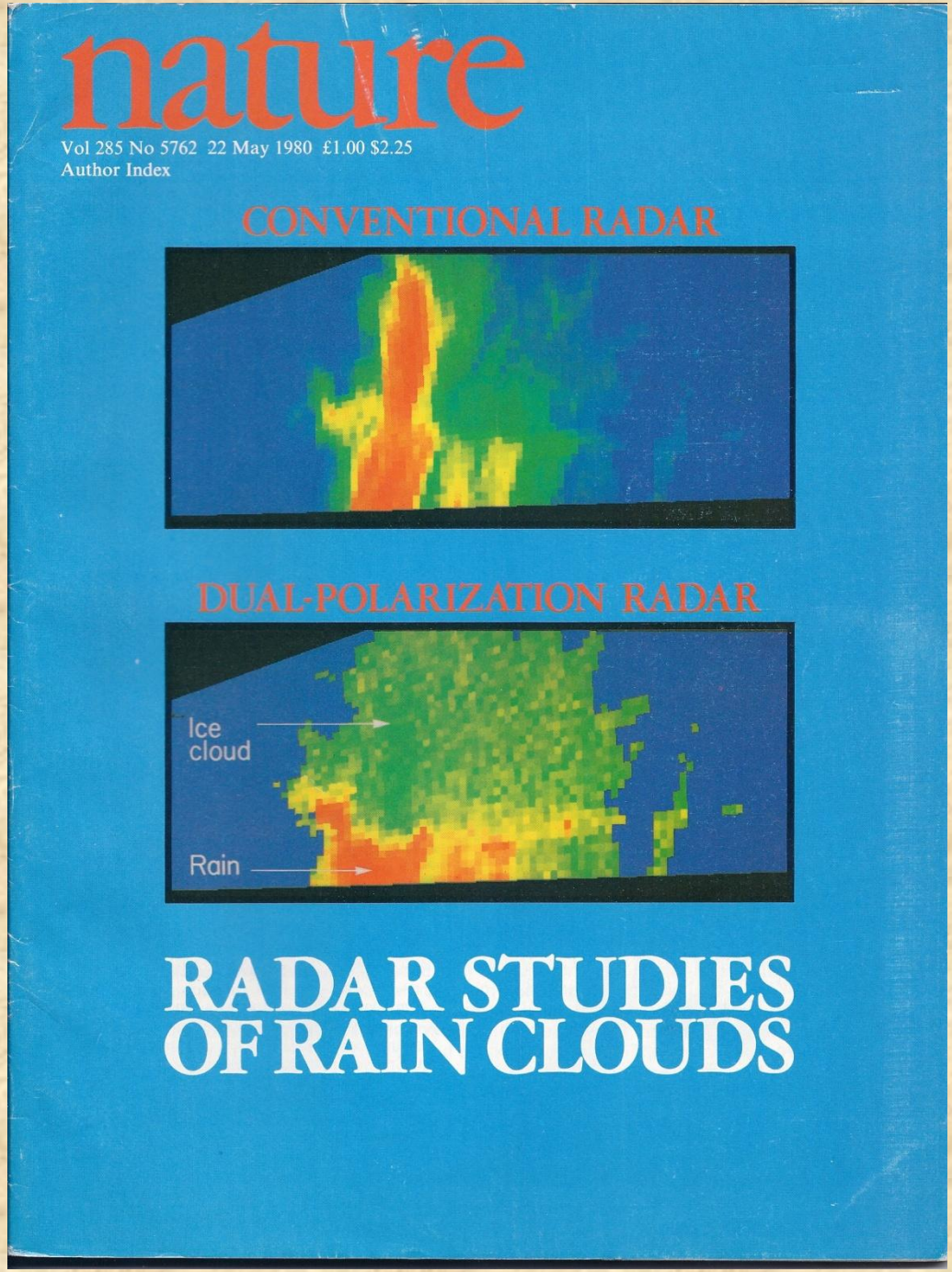




APPLETON LABORATORY ROTARY SWITCH

THE UK RUTHERFORD-APPLETON LABORATORY CHILBOLTON 3-CM DUAL POLARIZATION RADAR

http://www.stfc.ac.uk/Chilbolton/24821.aspx



MAY 1980 NATURE COVER SHOWING Z_H AND Z_{DR} RHI PROFILES OBTAINED WITH THE APPLETON LABORATORY CHILBOLTON RADAR

ARTICLES

Rain drop sizes and rainfall rate measured by dual-polarization radar

M. P. M. Hall, S. M. Cherry, J. W. F. Goddard & G. R. Kennedy

Rutherford and Appleton Laboratories, Ditton Park, Slough SL3 9JX, UK

A rapidly switched dual-polarization radar technique is used for the first time to obtain two-dimensional spatial distributions of the statistical characteristics of the sizes and concentration of rain drops in rain. These have been obtained using a high-resolution 10-cm wavelength radar, and the data have been used to estimate rainfall rates within small volumes to a much greater accuracy than is available from conventional radar measurements. The technique also gives a clear distinction between ice particles and rain drops.

THIS article shows some of the potential of a new radar technique that characterizes rather than assumes the distribution of rain drop sizes within a given volume, to estimate rainfall rates with improved accuracy. Many empirical relationships have been presented to compute rainfall rate from the measured reflectivity[1], but these relationships vary widely because they are governed by the statistical distribution of drop sizes at the time of measurement. This may not be significant if averaging rainfall over large volumes or long time intervals, but the assumption of an average statistical distribution to compute rainfall rates may result in a large error for applications where data are required for a small volume (for example, the pulse volume of a high-resolution radar) and without long time averages. To overcome this, the essential characteristics of the statistical distribution at a given time and place may be determined from independent measurements of the reflectivity factors obtained using vertical and horizontal polarizations[2]. The technique relies on the fact that large falling raindrops distort to become approximately oblate spheroids, each with its axis of symmetry near vertical, and that the degree of oblateness increases with drop size[3]. Consequently, the effective radar reflectivity factor measured using horizontal polarization is greater than that measured with vertical polarization.

We report here the first measurements of the two-dimensional spatial distribution of drop size characteristics using switching between polarizations which is sufficiently rapid to be regarded as simultaneous. This technique can substantially reduce errors in radar measurements of rainfall rate in small areas. Furthermore, the technique discriminates between regions of rainfall and dry ice particles. Dual-polarization radar data are expected to be of value in research fields such as radar meteorology, hydrology, cloud physics, radio science, communications engineering and erosion by hydrometeor impact.

The dual-polarization technique

Within a certain range of rain drop sizes, the numerical distribution of rain drops may be represented by an exponential function[1]. Such a function may be characterized by two parameters, N_0 and $\bar{D}$, such that:

$$N(D) = N_0 \exp(-D/\bar{D}) \qquad (1)$$

where $N(D)$ is the number of drops per unit volume per unit interval for which D is the diameter of the spherical drop with volume equal to the actual (distorted) drop, and $\bar{D}$ is the mean value of D. Here D and $\bar{D}$ are expressed in mm and $N(D)$ and N_0 in $\mathrm{mm^{-1}\,m^{-3}}$. Because of the drop distortion, and direct measurements usually being of drop volumes rather than their diameters, D_0(mm) is normally used, the diameter of that sphere for which half the volumetric water in the distribution comes from larger drops and half from smaller drops. $D_0 = 3.67\,\bar{D}$ as long as $D_0 \ll D_{\max}$, the diameter of the equivolume sphere of the largest drops[4].

Theoretical relationships based on work by Seliga and Bringi[2] estimate the parameters N_0 and D_0 from the effective reflectivity factors, $Z_{\mathrm{H,V}}$ ($\mathrm{mm^6\,m^{-3}}$), for horizontal and vertical polarizations and the differential reflectivity factor, Z_{DR}, which is defined as

$$Z_{\mathrm{DR}} = 10\log_{10}(Z_{\mathrm{H}}/Z_{\mathrm{V}}) \quad \mathrm{dB} \qquad (2)$$

The effective radar reflectivity factors are defined as

$$Z_{\mathrm{H,V}} = \frac{\lambda^4 \times 10^{18}}{\pi^5 |K|^2} \int_0^{10\,\mathrm{mm}} \sigma_{\mathrm{H,V}}(D) N(D)\,\mathrm{d}D \qquad (3)$$

where λ(m) is the wavelength, $K = (n^2-1)/(n^2+2)$ and n is

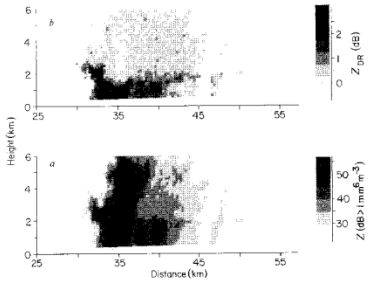


Fig. 1 Vertical scan through raincells at 13.17 UT on 15 August 1978. *a*, Absolute reflectivity factor, Z; *b*, differential reflectivity, Z_{DR}.

Nature Vol. 285 22 May 1980

nature

Dual polarization radar

from Thomas A. Seliga

EVER since the development of radar in the late 1930's and early 1940's, meteorologists and hydrologists have waited for the time when radar's full capabilities could be exploited for research and field operations. Progress from remote storm detection to assessment of storm characteristics has continued to the point where we can now estimate the drop size distributions of rainfall in a scattering volume (and, therefore, water content or rainfall rate), the nature of the hydrometeors producing the radar signal (whether ice particles or rain) and the bulk motion of the hydrometeors. In this issue of *Nature* Hall *et al.*[1] clearly demonstrate the first two kinds of measurement through use of the differential reflectivity (Z_{DR}) linear polarization scheme first proposed by Seliga and Bringi[2,3] for rainfall measurements. Pulsed Doppler radar techniques have also developed rapidly over the last fifteen years,[4,5,6] producing dramatic advances in our understanding of storm dynamics. This technique has been recently reviewed[6],so here the impact that polarization radar measurements like those of Hall *et al.* might have in a number of areas of meteorology and hydrology will be examined. It should be noted that Canadian scientists have also developed the use of circular polarization techniques and that their results too, are of great potential importance[7,8,9].

Hydrology

The accuracy of the Z_{DR} technique for measuring rainfall is expected to be of the order of 30% for a single observation at a single range gate. Since this measurement can be made within around a 200 ms time interval, and corresponds typically to an areal coverage of less than 0.5 $\mathrm{km^2}$ for modest size radar antennas at S-band wavelengths, large areal surveillance (of the order of 35,000 $\mathrm{km^2}$) with high spatial and temporal resolutions of rainfall will become possible.

The resultant benefits to hydrology are many: flash flood forecasting should become more reliable; study of the evolution of rainfall in different meteorological regimes and storm types will be possible, leading to improved description and classification of storms; understanding of topographical influences on rainfall should improve; watershed and stream flow modeling should progress; rainfall in semi-arid and arid lands should be more readily monitored; and, in future, hydrologic structures should be improved as a result of more accurate, detailed information on rainfall.

Thomas A. Seliga is Director of the Atmospheric Sciences Program and Professor of Electrical Engineering, Ohio State University, Ohio.

Cloud Physics

Possibly the most important application of Z_{DR} in meteorology will be in studies of the organization and structure of clouds and precipitation on the mesoscale and microscale.[10,11,12]. The ability to measure rainfall accurately from a single radar site independent of raingauge calibration, to follow the evolution of rainfall and its drop size distribution in space and time, and to accumulate and display data in real time, should provide new insights into our understanding of precipitation processes. Quantitative data of this type, when combined with Doppler data, will test the credibility of numerical cloud models and further their development. The second very important result of Hall *et al.*'s measurements is the ability to discriminate clearly between ice and water phase hydrometeors; this will lead to improved understanding of cloud development and precipitation formation. Important data on melting, drop breakup, and the development of raindrop size distributions, should also result from such measurements.

Climatology

The development of the Z_{DR} radar technique, which can provide accurate rainfall measurements over large areas, is very important for climatological studies, particularly within the context of the World Meteorological Organizations's World Weather Watch (WWW) and Global Atmospheric Research Programme (GARP) and their subprograms.[13,14]. For example, the recently conducted GARP Atlantic Tropical Experiment (GATE) and Monsoon Experiment (MONEX) would have benefited greatly had this radar capability been available and employed. Also, use of radar for ground truth measurements of rainfall intensity and cloud structure, particularly over the oceans, should aid in the development of reliable satellite methods of estimating rainfall over remote regions of the Earth's surface. Such data is indispensible for global weather studies and validation of general circulation and climate models. Moving to smaller scales, it is apparent that regional rainfall statistics should be largely improved as radars having polarization capability become operational.

Weather Modification

Whether human intervention can influence atmospheric conditions to enhance precipitation by significant amounts remains the foremost question in weather modification.[15] The importance of this problem is reflected by the Seventh World Meteorological Congress (1975) recent approval of a WMO Weather Modification Programme and Precipitation Enhancement Project (PEP).[16] Again, the importance of using the dual polarization radar technique in such programs becomes evident. Accurate rainfall measurements with high spatial (1 $\mathrm{km^2}$) and temporal (tens of seconds) resolutions over large areas (35,000 $\mathrm{km^2}$) and hydrometeor phase detection, are essential ingredients to any such effort. Hall *et al.*'s RHI grey scale plots of Z_{DR} and reflectivity and drop size distribution measurements show how the Z_{DR} radar might contribute to weather modification experiments. Indeed, one can contemplate using such radar data in case studies of seeded storms as a determinant for testing weather modification techniques. Whether this approach can supplant statistical methods of evaluation deserves serious attention. Another exciting role for dual polarization measurements in weather modification might arise from using Z_{DR} signatures of tracers released with seeding agents. Possible tracers include specially designed chaff and surfactants which significantly affect raindrop shape.

Other Applications

As noted by Hall *et al.*, the polarization radar should also have important applications in communications and erosion studies. Understanding the variability and characteristics of hydrometeors along terrestrial and satellite radio propagation paths is required for systems design while erosion, both of airborne vehicles and land surfaces, depends strongly on drop size distribution. Other possible applications might include studies of precipitation scavenging of airborne particles and pollutants, hail detection, detection and classification of severe storms, and aviation radar for detecting supercooled water droplets, a precursor to possible aeroplane icing conditions.

As more radars, modified to perform dual polariztion Z_{DR} measurements, become available, many of the above applications will be critically tested. The relative simplicity of the method and recent advances in high-power, microwave switching technology should enable many existing radar facilities to be modified at modest cost. This will offer many scientists opportunities to explore these ideas during this decade. The first measurements have produced dramatic results. Fulfilling all the hoped for applications is perhaps asking too much; being able to perform reliable, continuous and accurate measurement of rainfall would be enough! □

1. Hall, M. P. M., Cherry, S. M., Goddard, J. W. F. & Kennedy, G. R. *Nature* **285**, 195; 1980.
2. Seliga, T. A. & Bringi, V. N. *J. Appl. Meteor.* **15**, 69; 1976.
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11. Lilly, D. K. *Ann. Rev. Earth Planet. Sci.* **7**, 117; 1979.
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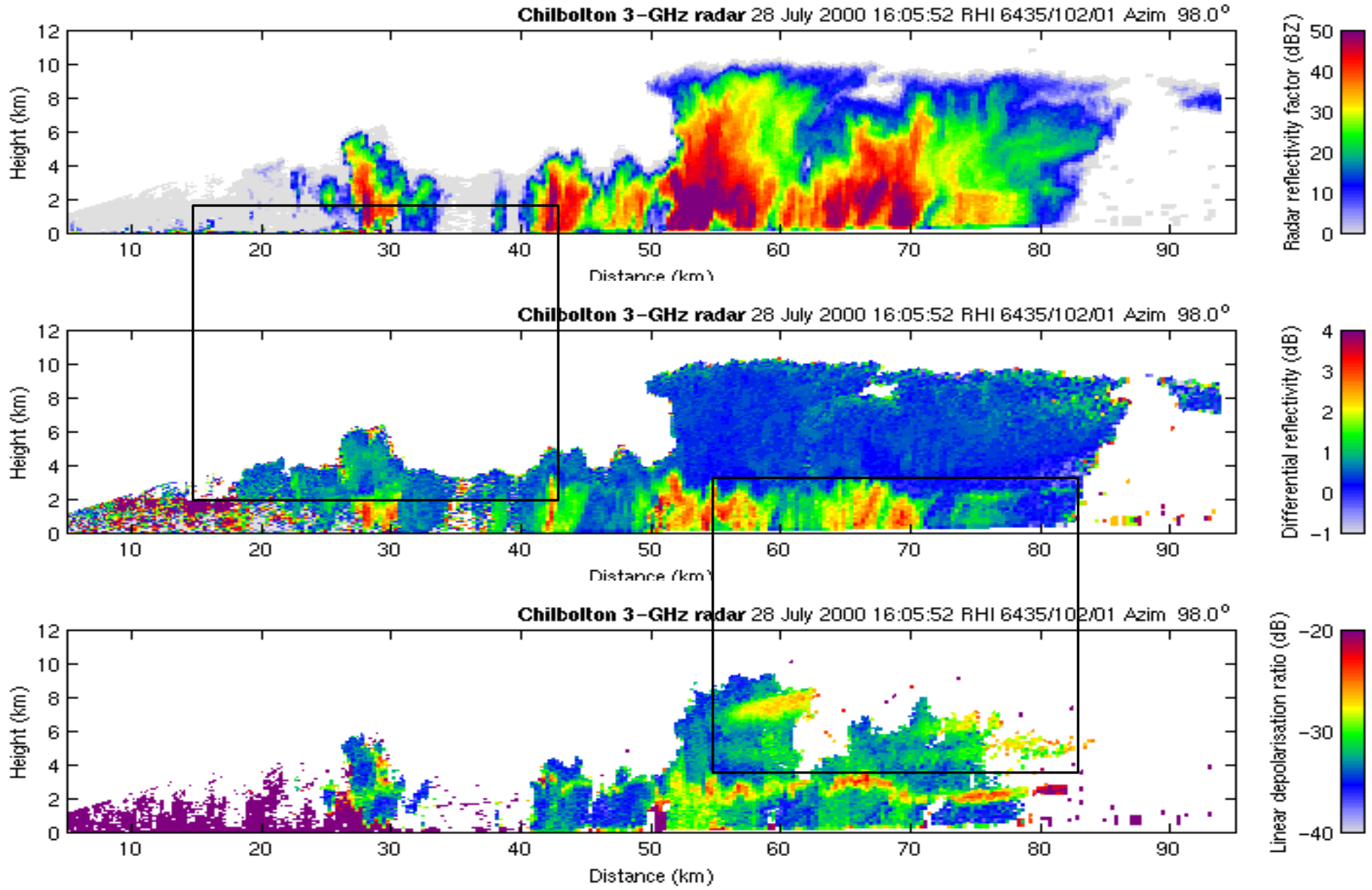
13. *Global Atmospheric Research Programme (GARP) Repts.* **1-21**, World Meteorol. Org., Geneva, Switzerland.
14. *GARP Atlantic Tropical Experiment (GATE) Repts.* **1-20**, World Meteorol. Org., Geneva, Switzerland.
15. Simpson, J., *Adv. Geophys.*, (ed. H. E. Landsberg; Academic Press, N.Y., 1-72, 1976.
16. *Precipitation Enhancement Project Repts. 1-17*, World Meteorol. Org., Geneva, Switzerland.

NATURE MAY 1980 PAPER BY MARTIN HALL ET AL. AND COMMENTARY BY TOM SELIGA ON IMPORTANCE OF DUAL POLARIZATION MEASUREMENTS IN HYDROLOGY, CLOUD PHYSICS, CLIMATOLOGY, WEATHER MODIFICATION PLUS A NUMBER OTHER APPLICATIONS



SAMPLE MULTI-PARAMETER DATA FROM THE CHILBOLTON RADAR OPERATED BY RUTHERFORD-APPLETON LABORATORY

UCAR NEWSLETTER

UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH

Volume 3, Number 3, MARCH 1979

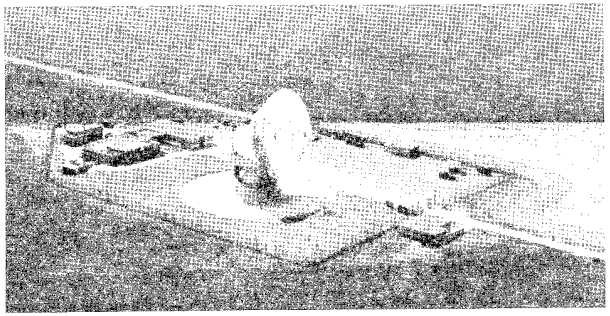
Ohio State Scientists View Rain from Another Angle

Two researchers at Ohio State University have developed a radar technique for determining the reflectivity of raindrops at two different polarizations (called "differential reflectivity") that may help determine such hard-to-assess parameters as raindrop size spectra and type of precipitation. Thomas Seliga, director of the Ohio State Atmospheric Sciences Program, and Viswanathan N. Bringi expect the technique to augment conventional radar measurements.

In 1975 Seliga and Bringi advanced a theory that rainfall rate could be inferred by using radar of a single wavelength and measuring the difference in radar reflectivity observed at two different polarizations, which they termed the differential reflectivity. The scientists also theorized that the type of precipitation could be determined from differential reflectivity. Falling raindrops in the atmosphere are usually nonspherical, resulting in polarization-dependent scattering properties. Previous observations showed that raindrops fall with preferred orientation. When the nonsphericity and preferred orientation of falling raindrops are integrated over a drop-size distribution, a given difference in the way the drops are scattering horizontally or vertically polarized signals should be observed.

If the degrees of nonsphericity and the preferred orientations are correctly estimated, the drop-size distribution may be inferred. If a drop-size distribution is known for a given time and its change with time can be found, it should be possible to derive rainfall rates and intensities as storm processes unfold.

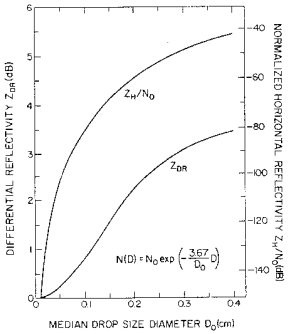
The two Ohio State researchers ran tests with the University of Chicago/Illinois State Water Survey radar in Oklahoma in the spring of 1977 and in Chicago in the summer of 1978, in England in 1977, and with the NCAR Convective Storms Division S-band (10 cm wavelength) radar in Grover, Colorado, in the summer of 1978.



Chilbolton Radar Facility of the Appleton Laboratory, Slough, United Kingdom, where measurements of differential reflectivity were made in the spring of 1978, using a fast switch to alternate between horizontal and vertical polarizations. Photo courtesy of M.P.M. Hall and S.M. Cherry, Appleton Laboratory.

In the tests, a storm of interest was first selected. The radar antenna was stopped to view a given elevation angle and azimuth angle, and the beam was switched on in normal horizontal polarization, turned off, switched on again in a vertical polarization, then turned off again. The entire on-off/on-off cycle was completed in a few seconds. Data were gathered for 20 s to 1 min, and the antenna was then raised to scan another elevation in the storm.

In storms with high reflectivities (>30 dBZ), the scientists found differences in radar scattering by raindrops between horizontally and vertically polarized signals, as predicted. According to Seliga, the results confirm that, assuming a certain drop distribution, the method can be used for remote measurement and quantification of rainfall intensity. He adds that it may one day be possible to detect conditions related to very heavy precipitation that leads to flash flooding, hydrometeor phases in storm development, formation of damaging hail, and degree of storm severity. The method could also lead to a better understanding of cloud physics and to better monitoring of the effects of weather modification.



Theoretical basis for using differential reflectivity to determine parameters of an exponential drop-size distribution in rain.

Seliga and Bringi visited Appleton Laboratory in England last fall to collaborate in the use of a system of rapid switching of polarization using the Chilbolton 10 cm radar; the switching system was designed and constructed on the basis of their theoretical work. The British device does not require that the radar be turned off between switches in polarization (this is required of other radars to avoid electrical sparking or arc

MARCH 1979 UCAR NEWSLETTER DESCRIBING DUAL POLARIZATION TECHNOLOGY

NEW YORK TIMES PRESS RELEASE

Science Watch; Rain Radar

New York Times (1857-Current file). New York, N.Y.: Jun 12, 1979. pg. C3, 1 pgs

Abstract (Document Summary)

A radar technique that measures both the size and number of falling raindrops may give meteorologists more accurate estimates of the rainfall in storms, the National Science Foundation reports. Such accurate information on rainfall would be a significant aid in flood prediction among other things.

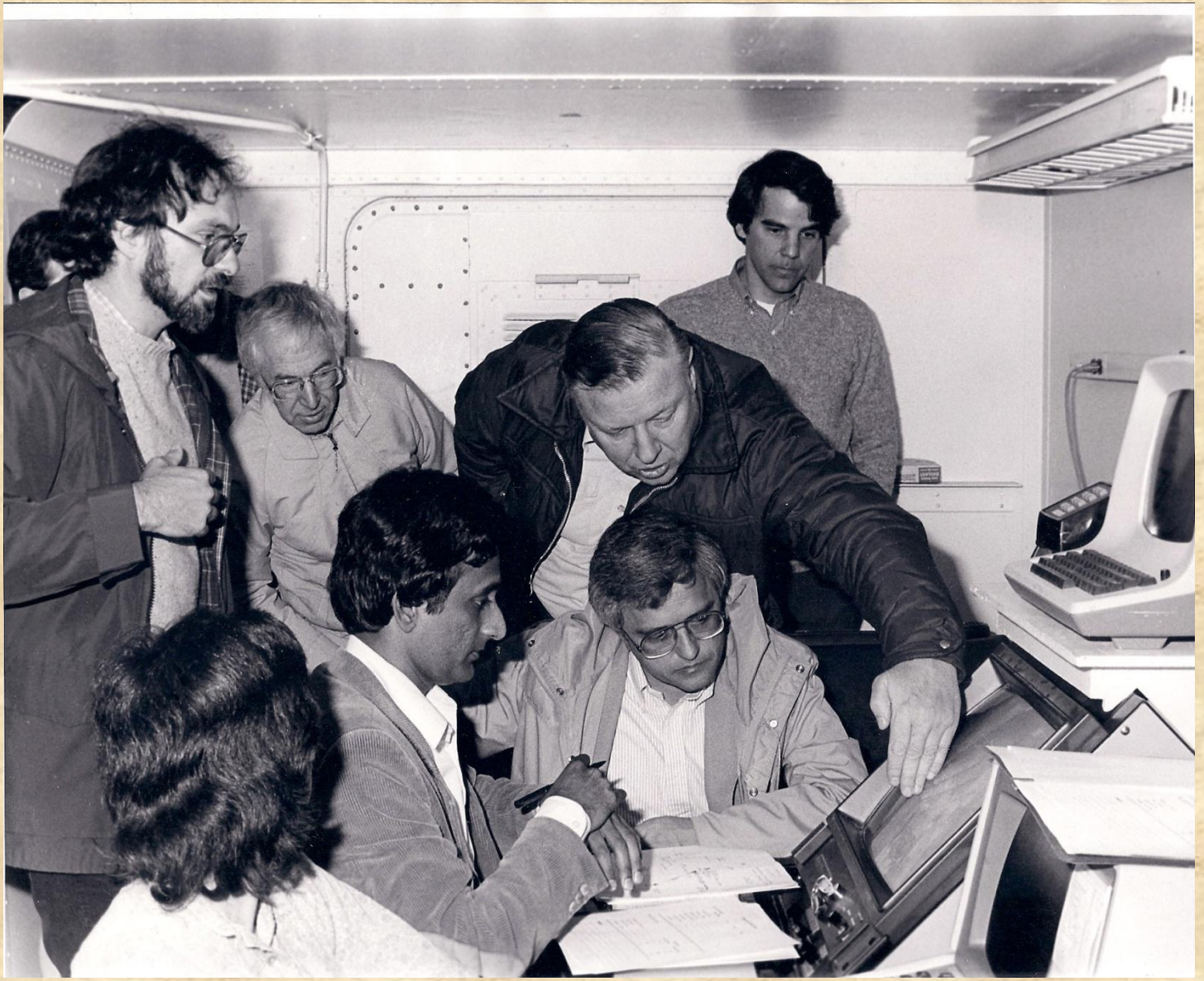
IMPROVING UNDERSTANDING AND DEMONSTRATING APPLICATIONS

Bringi, V. N., T. A, Seliga and M. G. SriRam, 1980: Statistical Characteristics of the Differential Reflectivity Radar Signal, 19th Conf. on Radar Meteorology.	Z_{DR} STATISTICS, INCLUDING CROSS-CORRELATION COEFFICIENT
Seliga, T. A., V. N. Bringi and H. H. Al-Khatib: 1982: A Preliminary Study of Comparative Measurements of Rainfall Rate Using the Differential Reflectivity Radar Technique and a Raingage Network, J. Appl. Meteor.	USE OF R(Z, Z_{DR}) FOR IMPROVING RAINFALL RATE ESTIMATION VS. R(Z)
Bringi, V.N., T. A. Seliga and E.A. Mueller, 1982. Comparison of Rainfall Rates Derived from Differential Reflectivity and Disdrometer Measurements, Trans. IEEE Geoscience and Remote Sensing , GE-20, No. 2, 201-209.	USING (Z, Z_{DR}) TO INFER DROP SIZE PARAMETERS (N_o, D_o)
Seliga, T.A., K. Aydin, C.P. Cato and V. N. Bringi, 1982: Use of the Radar Differential Reflectivity Radar Technique for Observing Convective Systems, In Cloud Dynamics , Ed. E. M. Agee/T. Asa.	DUAL POLARIZATION MEASUREMENTS IN CLOUD PHYSICS
Cooper, W. A., V. N. Bringi, V. Chandrasekar and T.A. Seliga, 1983. "Analysis of Raindrop Parameters Using a 2-D Precipitation Probe with Application to Differential Reflectivity (Z_{DR})," Proc. 21st AMS Conference on Radar Meteorology, Edmonton, Sept. 19-23.	HORIZONTALLY-ORIENTED 2-D PROBES ON AC CONFIRMED DROP SHAPES WITH SMALL OSCILLATIONS AND CANTING

BREAK POINT

1982: Open Symposium on Multiple-Parameter Radar Measurements of Precipitation, URSI Commission F, Bournemouth, UK.	STATUS OF DUAL POLARIZATION
Hall. M.P. M., 1984: Special Papers- Multiple-Parameter Radar Measurements in Precipitation, 27 Papers on Polarization., dealing with rainfall rate measurements, hydrometeor characterization, effects of raindrop shapes, hail detection, circular and linear polarization, propagation effects, drop oscillations, antenna effects, etc.	RELATED PUBLICATIONS
Aydin, K. and T. A. Seliga, 1984: Radar Polarimetric Backscattering Properties of Conical Graupel, J. Atmos. Sci., 41, No. 11, 1887-1892.	QUALITATIVE HYDROMETEOR CHARACTERIZATION
Seliga, T. A., K. Aydin and H. Direskeneli, 1984: Comparison of Disdrometer-Derived Rainfall and Radar Parameters with Differential Reflectivity Radar Measurements during MAYPOLE '83, Preprints 22nd AMS Conf. on Radar Meteor., 10-13 September, 358-363.	EXCELLENT AGREEMENT BETWEEN RADAR AND GROUND-BASED RAINFALL

OBSERVING FIRST DUAL POLARIZATION DATA FROM THE NCAR CP-2 RADAR - 1983



Aydin, K., T. A. Seliga and V. N. Bringi, 1984: A New Dual Wavelength Hail Signal Derived from Differential Reflectivity (Z_{DR}) Dual Polarization Radar Measurements: Comparison with the ZDR Hail Signal in MAYPOLE '83, Preprints 22nd AMS Conf. on Radar Meteor., 10-13 September, 409-414.	UTILITY OF DUAL POLARIZATION MEASUREMENTS IN THE INTERPRETATION OF DUAL WAVELENGTH SIGNALS
Bringi, V. N., T. A. Seliga, and K. Aydin, 1984: Hail Detection with a Differential Reflectivity Radar, Science, 225, 1145-1147.	GROUND TRUTH VALIDATION OF HAIL DETECTION USING (Z, Z_{DR})
Mueller, E. A., 1984: Calculation Procedures for Differential Propagation Phase Shift, Preprints 22nd AMSConference on Radar Meteorology, 10-13 September, 397-399.	METHODOLOGY FOR COMPUTING DIFFERENTIAL PHASE SHIFT

NATIONAL OCEANIC AND ATMOSPHERIC ADMINSTRATION

- **2012: Life-saving technology upgrade coming to a Doppler radar near you**
  - **Alerted the public to implementation of a 'new technology' termed dual polarization**
- **2013: Dual-polarization radar: Stepping stones to building a Weather-Ready Nation**
  - **Announced completion of the program**

NOAA CLAIMED THAT THEY DEVELOPED THE TECHNOLOGY THROUGH DECADES OF RESEARCH AT ITS NATIONAL SEVERE STORMS RESEARCH LABORATORY (NSSL)

WHAT REALLY HAPPENED?

- **2012: Life-saving technology upgrade coming to a Doppler radar near you**
  - **Alerted the public to implementation of a 'new technology' termed dual polarization**
- **2013: Dual-polarization radar: Stepping stones to building a Weather-Ready Nation**
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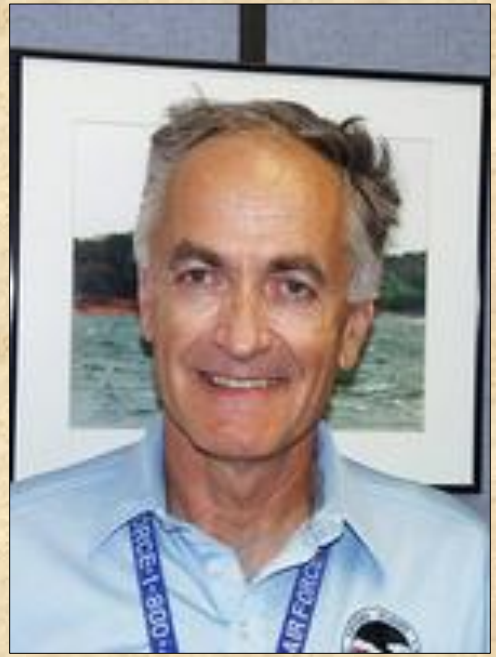
RADAR'S NEXT PHASE by Bob Henson, University Corporation for Atmospheric Research - National Center for Atmospheric Research (UCAR/NCAR) March 11, 2011

Dual polarization holds promise for both research and weather forecasting

The Path to Polarization – information provided by Dusan Zrnić of NSSL



NSSL'S EARLIEST INVOLVEMENT WAS IN 1979 WHEN Richard Doviak and Dusan Zrnić traveled to ALBERTA, CANADA in 1979. INDICATED THAT THE PIONEERING WAS by McGill University .

- ***The Canadian pioneering was actually led by Glen McCormick and Archie Hendry of the National Research Council (NRC) with additional involvement of the Alberta Research Council and McGill University. The latter was through dissertation research by Brian Barge and Robert Humphries.***

- ***NSSL was approached by Seliga and Bringi in 1979-80 to collaborate in dual polarization studies, but they declined to fund our very modest proposal.***

TRYING TO CONVINCE NASA WALLOPS ISLAND, NCAR, ISWS/UC, NSSL, USAF OF THE IMPORTANCE OF VALIDATING Z_{DR}

- ***NSSL decided to modify its own radar for dual polarization studies in 1983-84, based on linear polarization basis. The concept of Z_{DR} was reported by Seliga and Bringi at an URSI Meeting in 1974 and published in 1976.***

- ***In 1985 NSSL claimed to have developed and tested a technology that transmits both horizontally and vertically polarized pulses on the Cimarron radar. They discover this capability provides valuable information about the type and amount of precipitation that is falling and call it dual-polarization technology.*** **(http://www.nssl.noaa.gov/about/history/).**

  - **This technology *was included in the 1976 paper by Seliga and Bringi.***
  - ***Discoveries were common knowledge within the weather radar community.***
  - ***NSSL did not originate the dual polarization terminology.***

THE DUAL POLARIZATION TECHNOLOGY WAS VALIDATED BASED ON MEASUREMENTS MADE BY GENE MUELLER OF THE ILLINOIS STATE WATER SURVEY USING THE CHILL RADAR IN OKLAHOMA IN 1977.

- ***Gene Mueller was the only person in the radar community who was willing to assist us in our attempts to perform experiments to validate the dual polarization hypothesis.***

- ***The first, very important, validation data were obtained in Oklahoma, but only after the NSSL field project was concluded. NSSL scientists prohibited us from using the radar in a dual polarization mode during the project, even during extended periods of time when the CHILL Radar and other facilities were idle.***

NSSL STARTED TO WORK ON DUAL POLARIZATION IN EARNEST IN THE MID-80'S.

- ***A large body of work on measuring rainfall and distinguishing rain from hail and other hydrometeors had already been performed and reported on ourselves and others.***

- ***The evolution of the NEXRAD radar program was documented in by Captain J. David Bonewitz of the NEXRAD Joint System Program Office at the 20th Conference on Radar Meteorology in Boston, MA in 1981. Given the dual polarization research results we and others had already obtained and reported on, I challenged the community at this Conference to include dual polarization capability on the NEXRAD radar system.***

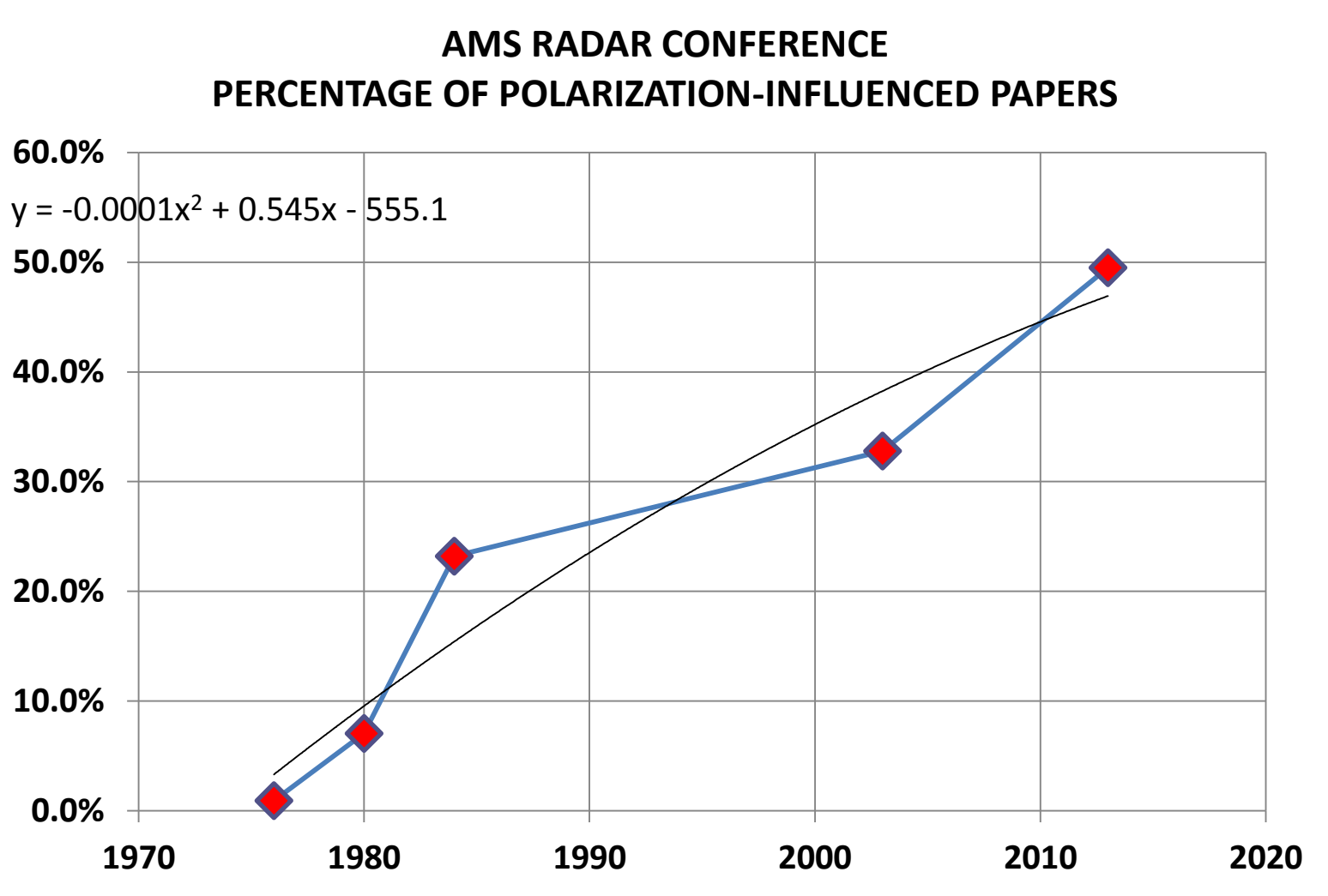
”NCAR was another dual-pol pioneer, converting its CP-2 radar and creating the first real-time displays of differential reflectivity (relating horizontal to vertical returns).”

- ***NCAR’s charter and mission.*** ***http://www2.ucar.edu/about-us#ncar***
- ***The TRUE DUAL-POL pioneers were the University of Illinois State Water Survey, the NRC of Canada and its McGill collaborators, the DLR in Oberpfaffenhofen, Germany, the Appleton Laboratory in the UK and the Institute of Atmospheric Sciences and Climate (CNR) of Italy.***
- ***NCAR’s CP-2 conversion was primarily dependent on a switch provided by Ohio State and support from the Army Research Office, not NSF base support to NCAR.***

THE LATEST NWS CLAIMS ON THE IMPACT OF DUAL POLARIZATION

1. Products
   - Z_{DR} - Differential Reflectivity
   - CC - Correlation Coefficient
   - Kdp - Specific Differential Phase Shift
   - HC - Hydrometeor Classification Algorithm
   - ML - Melting Layer
   - Precip - (DPR, PRE, OHA, DAA, STA, DUA, DOD, DSD, HHC)
2. Applications
   - Winter Weather
   - Hail Detection
   - Heavy Rain Detection
   - Tornadic Debris Signatures
   - Updraft Detection (Z_{DR} Columns)
   - Non-Precipitation Echoes

http://www.wdtb.noaa.gov/courses/dualpol/trainingaid/index.htm



RESEARCH IN DUAL POLARIZATION RADAR METEOROLOGY NOW DOMINATES ALL OTHER TECHNOLOGIES, NOT COUNTING THE EUROPEAN CONFERENCE ON RADAR IN METEOROLOGY AND HYDROLOGY!! THIS DEVELOPMENT IS ATTESTED TO BY THE WORLD-WIDE COMMERCIALIZATION AND IMPLEMENTATION OF THESE SAME CAPABILITIES IN OPERATIONAL WEATHER RADAR SYSTEMS.

IMPACTING THE PRESENT AND FUTURE

- Characterizing hydrometeor types throughout storm volumes, including capabilities to
  - Discriminate between water and ice phase
  - Detect and classify hail
  - Map hydrometeor particle types in storms
  - Locate and gauge aircraft icing potential
  - Gauge rainfall drop size distribution parameters
  - Improve the quantitative estimation of rainfall intensity
  - Lead to reliable ways of estimating snowfall intensity
  - Locate and track snow and rainfall boundaries
  - Improve understanding of storm evolution
  - Obtain more accurate and longer duration storm nowcasts
  - Lead to better ways of predicting storm-based turbulence and microbursts
  - Automate the detection and interpretation of the melting layer

AND THE LIST GOES ON

- Detecting low-altitude water vapor for early prediction of storm initiation
- Remotely sensing aircraft icing conditions through detection of large super-cooled droplets and other hydrometeor forms
- Detecting occurrences of anomalous propagation-based false weather echoes
- Detecting and discriminating insects and aviary-based echoes from weather
- Detecting and nowcasting wet and dry microbursts
- Detecting and characterizing tornadoes
- Identifying and locating the presence of intense electric fields in clouds

AND ON

- Detecting false echoes due to chaff
- Detecting and discriminating dust and sand from weather echoes
- Mitigating against effects caused by partial beam blockage
- Improving the initiation state of mesoscale numerical models
- Characterizing intensity of convection and its development
- Hypothesizing, testing and validating cloud physics phenomena
- Estimating the effectiveness of rainfall and other hydrometeorological-based means of cleansing the atmosphere
- Evaluating the efficacy of weather modification technologies

PROFESSOR SAAD NAGI
OHIO STATE SOCIOLOGIST
A CONCEPT TO PONDER

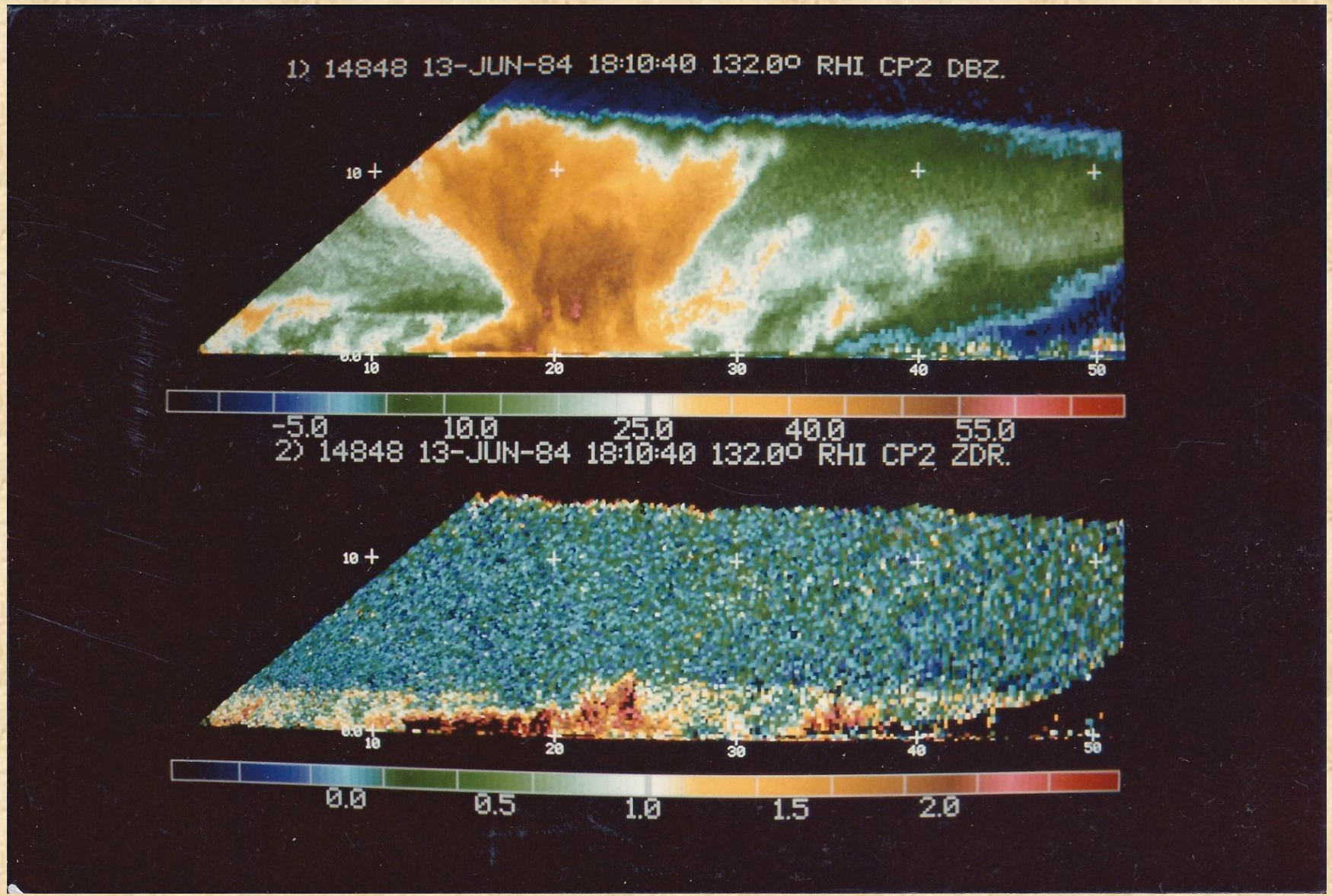
“For effective solutions to pressing problems, understanding of the dynamics of knowledge and technology is essential.”

I HOPE YOU AGREE WITH ME?

DR. WAYNICK AND HIS IONOSPHERIC RESEARCH LABORATORY'S CONTRIBUTIONS WENT FAR BEYOND THE MANY EVIDENT SCIENTIFIC ADVANCES IN THE FIELDS OF RADIO WAVE PROPAGATION AND UPPER ATMOSPHERIC PHYSICS . IN THIS INSTANCE, THEY WERE ALSO KEY TO THE CONCEPTUALIZATION AND DEVELOPMENT OF THE SOCIALLY-RELEVANT, WORLD-WIDE UTILITY OF DUAL POLARIZATION WEATHER RADAR TECHNOLOGY.

Thank you for your attention.

I would be happy to respond to any questions.


1) 14848 13-JUN-84 18:10:40 132.0° RHI CP2 DBZ.
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2) 14848 13-JUN-84 18:10:40 132.0° RHI CP2 ZDR.
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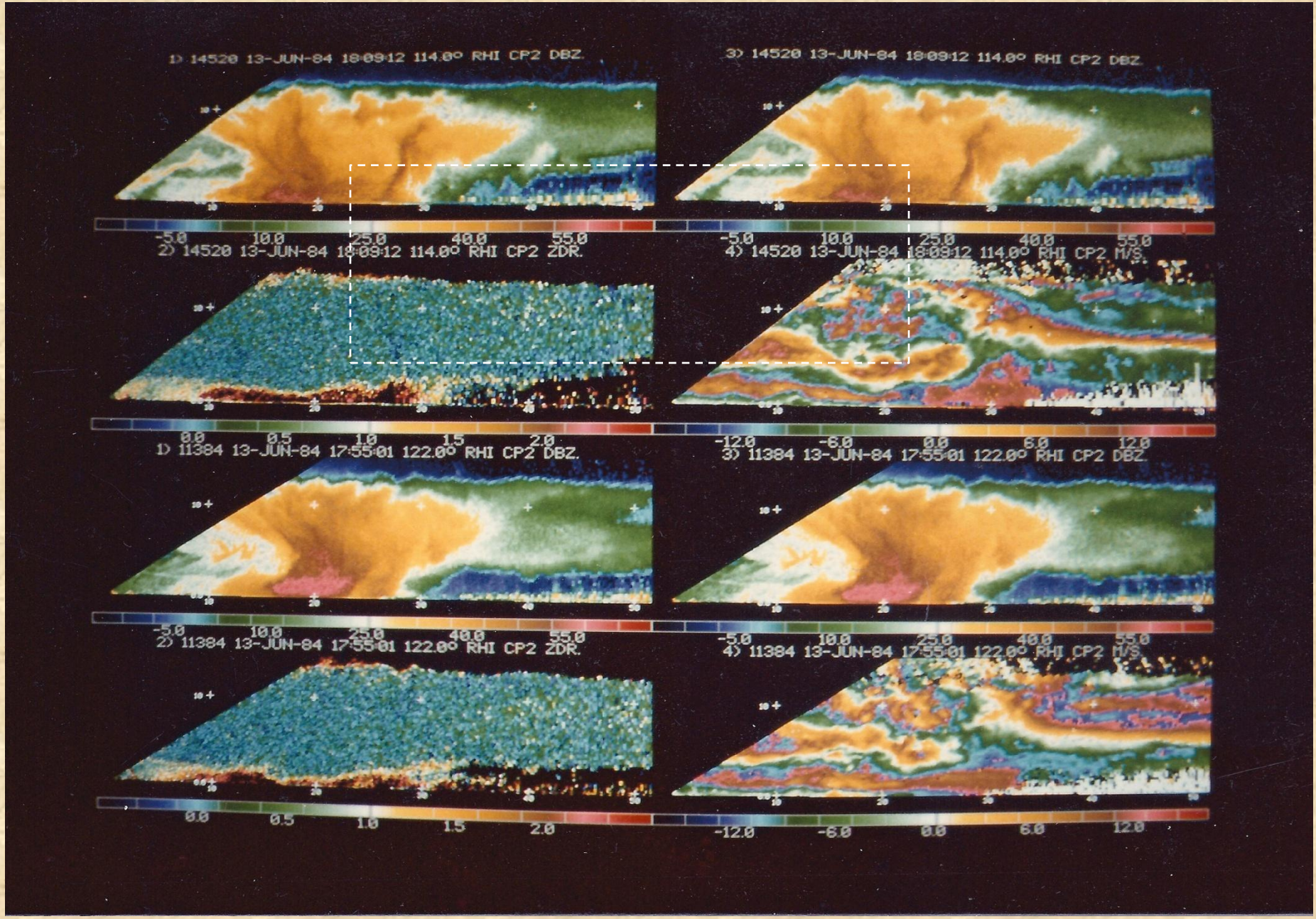
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3) 14520 13-JUN-84 18:09:12 114.0° RHI CP2 DBZ.
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2) 14520 13-JUN-84 18:09:12 114.0° RHI CP2 ZDR.
4) 14520 13-JUN-84 18:09:12 114.0° RHI CP2 M/S.
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1) 11384 13-JUN-84 17:55:01 122.0° RHI CP2 DBZ.
3) 11384 13-JUN-84 17:55:01 122.0° RHI CP2 DBZ.
-5.0 10.0 25.0 40.0 55.0
2) 11384 13-JUN-84 17:55:01 122.0° RHI CP2 ZDR.
4) 11384 13-JUN-84 17:55:01 122.0° RHI CP2 M/S.
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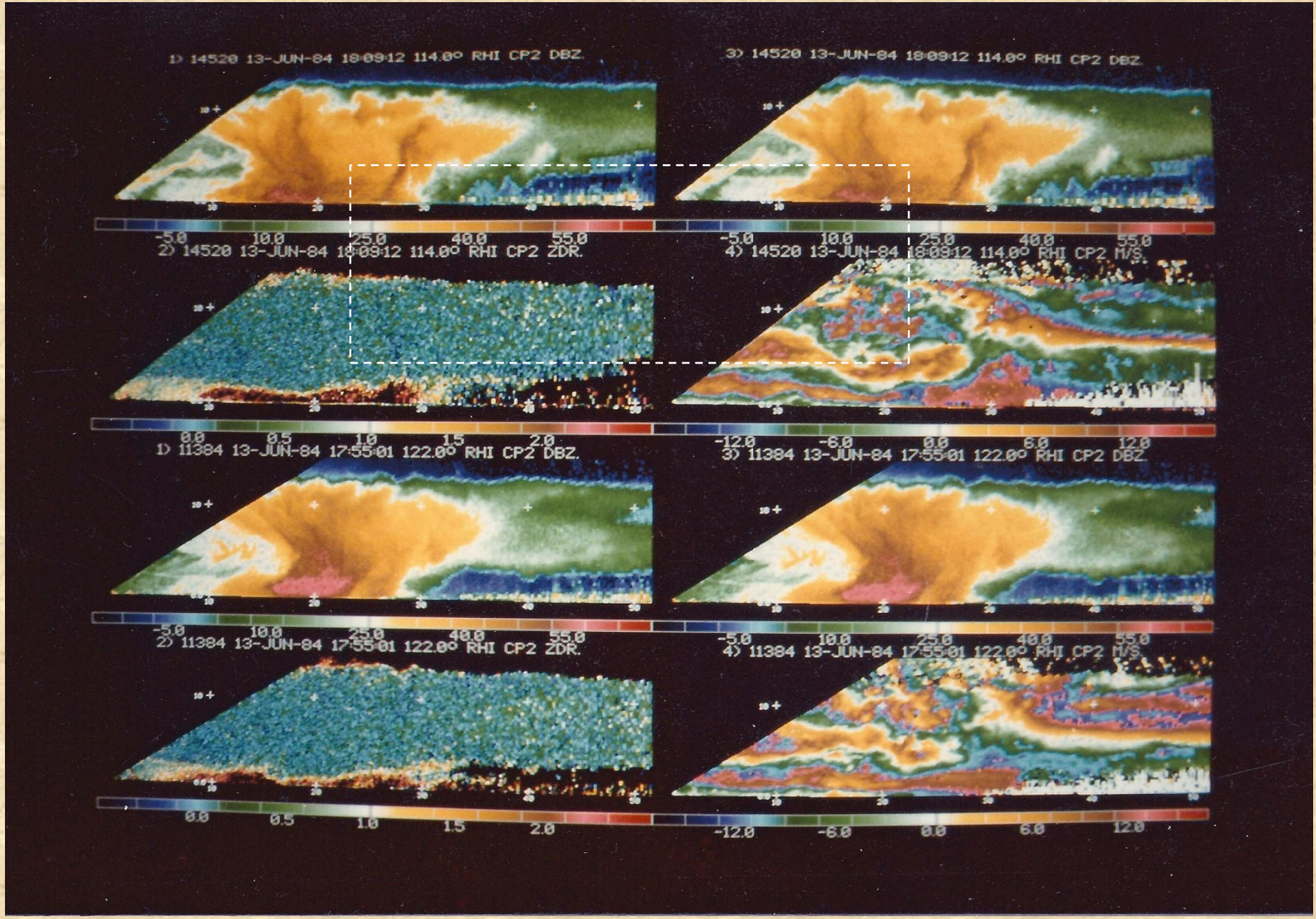
Z_H , Z_{DR}

Z_H , V_D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Z_H , Z_{DR}

Z_H , V_D